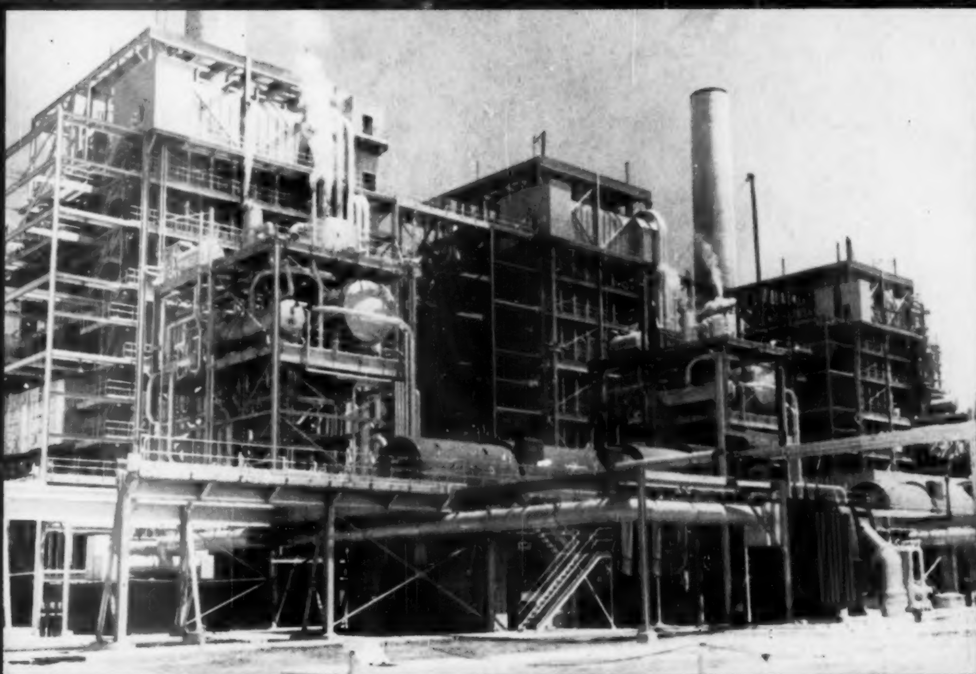
COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

July 1959



View of lignite burning units at Sandow Plant of Texas Power and Light Co. described on p. 34. Note the use of an all aluminum casing.

Burning Lignite and Char in Power Boilers

Criteria For Equipment Reliability

Air Preheat on Industrial Boilers

COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

Vol. 31 **No. 1**

July 1959

Feature Articles

Editorials

Departments

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BPA

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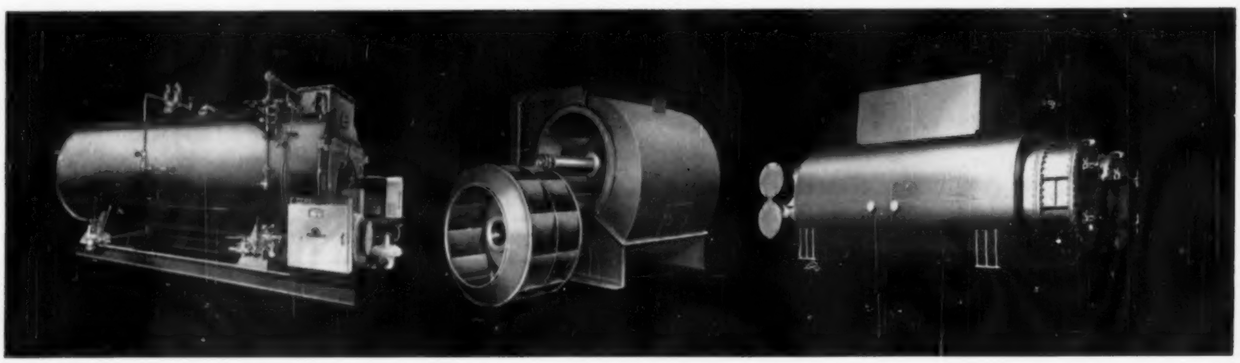
Ready for



Firebox, scotch-type, and package boilers for heat, steam, and industrial power.

Mechanical draft fans for induced and forced draft duty in power plants.

Balanced-flow surface condensers for condensing turbo-generator exhaust steam.

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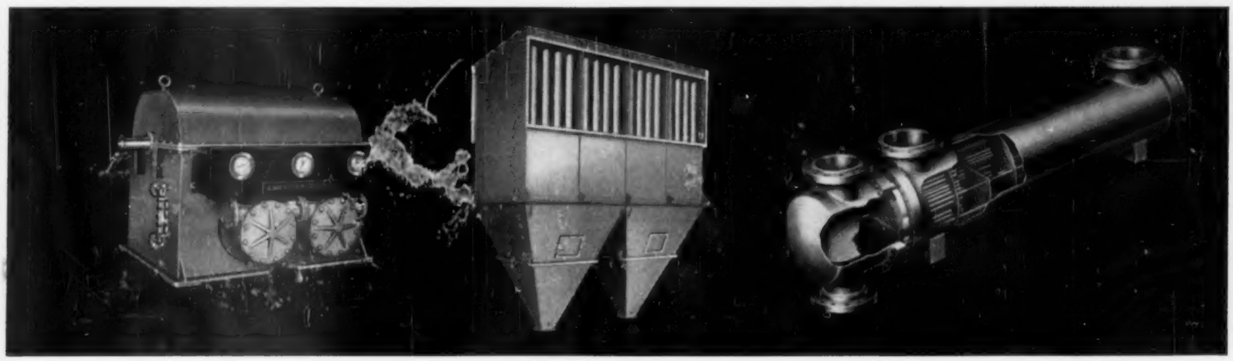
HERE'S WHY: You get *one-source responsibility* for quality and performance in equipment designed, engineered, and manufactured to work together. Combining three American-Standard* divisions—American Blower, Ross Heat Exchanger, Kewanee Boiler – the new Industrial Division encompasses the six major fields of air conditioning, heating, ventilating, heat transfer, dust collection, and fluid drives. Contact our nearest office. American-Standard Industrial Division, Detroit 32, Michigan. In Canada: American-Standard Products (Canada) Limited, Toronto, Ontario.



Fluid drives for adjustable-speed control of feed-pump flow and fan volume.

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What's New from Edward Valves

New Products . . . Solutions to Problems . . . Information on Steel Valves from Edward, Long-Time Pioneer in the Field!

HOW TO SELECT FORGED STEEL VALVES

When you need forged steel globe or angle valves (2½" and smaller) for high-pressure and/or high-temperature applications, you can save money on your installations as well as reduce future maintenance expense by making sure you select the proper valve. Here are a few suggestions.

VALVE CONSTRUCTION DETAILS
(See large illustration, opposite page)

Valve Handwheel or Handle should be large enough to operate valve easily. Wheel spokes help keep handwheel cool. Knobbed design permits tight grip even with greasy gloves. Impact type handle will be helpful in obtaining tight closure for valves 1½ to 2½ in.

Yoke Bushing material should be checked. High-strength aluminum bronzes are usually best. Look for ample thread engagement between bushing and yoke and between bushing and stem.

Gland-Stuffing Box—Stuffing box with bolted gland assures good packing compression; hinged bolts swing out of the way but don't get lost. Be sure to get stainless steel bolts for maximum resistance to rusting, and for easy adjustment even after years of service. Packing chamber should be deep and not excessively wide.

Bonnet Joint of bolted construction is easiest to work with. You can disassemble and reassemble with pocket-size tools. Union bonnet is compact and usually less expensive for smaller valve sizes, but is not recommended for high temperatures. Bonnet gasket of soft iron performs well in most services but spiral wound metallic-asbestos gaskets are superior in high temperature services. For extreme pressure-temperature services welded bonnet joints for permanent tightness are desirable. Seal-welded type bonnet has advantage over fully welded design because it permits disassembly and reassembly.

Seat-Disk Joint—An integral hard-faced seat is generally regarded as superior to screwed seat construction because it eliminates body-seat leakage and retains hardness under temperature. A hard faced disk or disk of special alloy is desirable in high temperature services; but 13 per cent chromium stainless steel is an excellent all purpose material below 750 F.

Other Features to Evaluate—Valve compactness is important because you frequently find small piping located in crowded quarters. Inclined bonnet globe valves are less likely to erode due to high velocities—have less pressure loss. Valves of "inside screw" design (stem threads below packing chamber) are usually lower priced and give good service where temperature is not too high and where line fluids are free of sediment. But, best design and materials are useless without experienced workmanship and rigid quality control.

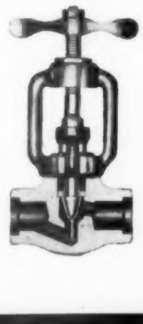
VALVE APPLICATION SUGGESTIONS

First, determine whether a standard valve will do the job before ordering expensive special designs. (Your Edward Representative can help you decide.) Often a slight modification of a standard valve, or a combination of standard valves, will do the job. Here are some facts about types of standard valves and their application:

- For many services, angle valves (illustrated by valve #1) reduce installation cost, minimize pressure drop, improve operational convenience. All Edward forged steel stop and stop-check valves from ¼" to 2½" sizes are available in the angle version.
- For high temperature, Edward forged steel valves with seal-welded bonnets (#2) permanently maintain pressure tightness without periodic tightening of bonnet joints.
- For blow-off service, or wherever double valving is required, select sets of valves of the same basic type with hard-faced seating surface for dependability, longer life and interchangeability of parts (#3).
- For permanent tightness, select an instrument valve (#4) with corrosion-erosion resistant hard-faced seat or a valve with stainless steel body. Bonnetless design requires less maintenance.
- Piston-type check valve (#5), available with union, bolted, or seal-welded cover, is best for most services because it will seat tighter, has easily repairable seat face.
- Modern globe and angle stop valves (shown here) are more dependable than gate valves where repeated drop-tight closures are required, may be used for approximate flow regulation and moderate throttling.

YOUR EDWARD REPRESENTATIVE will be glad to give you the complete story on these features, plus the many other advantages of Edward valves—such as positive, pressure-tight backseats, self-centering disks, special stem and packing materials, and many others. Edward builds a complete line of cast and forged steel valves for pressures to 10,000 lbs. For additional information write to Edward Valves, Inc., 1206 W. 145th Street, East Chicago, Indiana. Subsidiary of Rockwell Manufacturing Company. Represented in Canada by Lytle Engineering Specialties, Ltd., 360 Notre Dame St., W., Montreal 1, Quebec.

4 INSTRUMENT VALVE—Fig. 952Y, 600 lb or 2500 lb at 850 F (6000 lb WOG) with swing bolted gland, socket welding ends, no bonnet joint. Sizes ¼" to 1".



5 CHECK VALVE—Fig. 5538, piston type, 1500 lb at 1050 F (3600 lb WOG) bolted bonnet, screwed ends, integral Stellite seat. Sizes ¼" to 2".

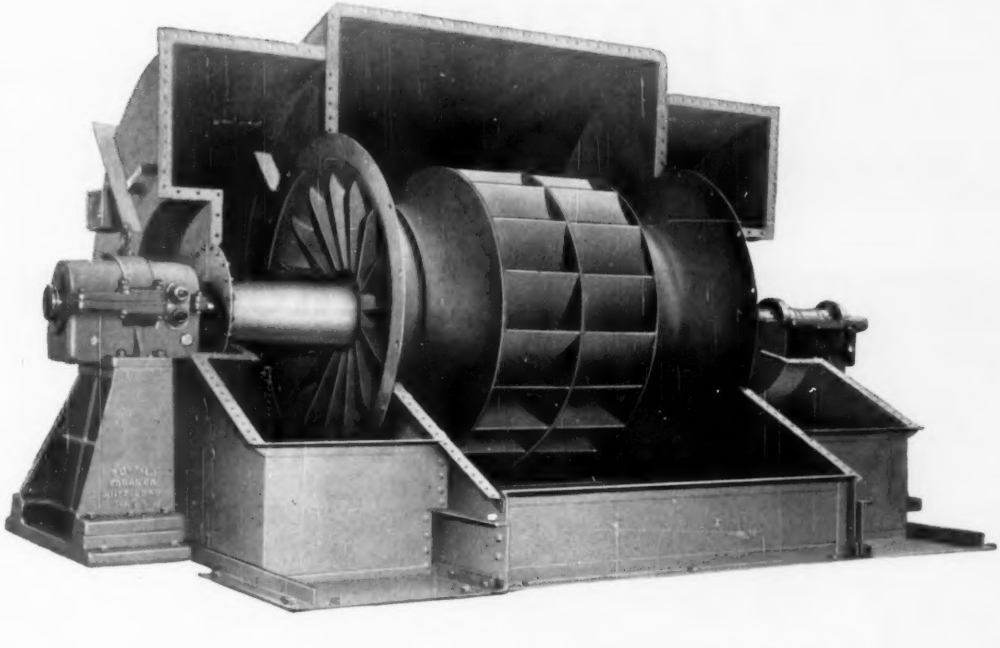
*T. M. Reg. U. S. Pat. Off.

EDWARD STEEL VALVES

another fine product by

ROCKWELL

Catalog 14 contains full data on the complete Edward line of forged and cast steel valves from ¼" to 18"; in globe and angle stop, gate, non-return, check, blow-off, stop-check, relief, hydraulic, instrument, gage and special designs; for pressures up to 10,000 lbs: with pressure-seal, bolted, union or welded bonnets, with screwed, welding or flanged ends.



"Buffalo" Airfoils are Available in Capacities in Excess of One-Half Million CFM, Pressures to 80" Water.

"BUFFALO" AIRFOILS COST LESS TO OPERATE ...REQUIRE LESS MAINTENANCE

HERE'S WHY: If you are considering the use of airfoil fans for mechanical draft service, ponder these facts regarding the "Buffalo" Airfoil.

With an extremely broad static efficiency curve, as compared to most competitive airfoil designs, the "Buffalo" Airfoil definitely costs less to operate. Major factors governing this efficiency are—a completely streamlined inlet with inlet bell and wheel flange forming a true half-circle —fixed or variable inlet vanes, where used, are placed well into the inlet throat to fully utilize horsepower reducing spin developed by the vanes — generous inlet boxes with external bracing give low entry loss — airfoil wheel incorporates proper blade passages for best air-flow through the wheel—scroll shape lets air stream from blade passages to housing channel with greatest ease — divergent outlet provides optimum static regain from cut-off.

This top efficiency, combined with the famous "Buffalo" "Q" Factor* Construction for a longer life with less maintenance, makes the "Buffalo" Airfoil best suited for this specialized service. For full details phone your Buffalo Engineering representative or write for Bulletin FD-905.

**The "Q" Factor — the built-in Quality which provides trouble-free satisfaction and long life.*

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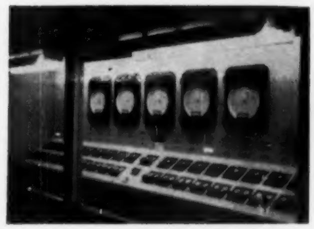
HAGAN NEWSLETTER
Behind the Panel



CONTROLLED ATMOSPHERE FURNACE--WITH A CONTROLLED ATMOSPHERE

Very special high silicon steel sheets, to be used for transformer cores, are annealed in a furnace using hydrogen as a reducing atmosphere to remove occluded moisture and other impurities. A Hagan furnace pressure control system, specially designed for this application, has produced some interesting results. Tests have shown that, with Hagan's precision control, hydrogen flow can be reduced during certain times in the annealing cycle, with a consequent saving in hydrogen amounting to $12,000 annually, more than enough to pay for the controls the first year. But a much more important result is the general upgrading of product. In fact, recent checks have shown that quality of the product was improved by 200%. (Item G-1)

WASHDAY PROBLEM SOLVED . . . BY A HAGAN DUST COLLECTOR

A college high in the Rockies was so situated that flyash from the boiler showered the whole valley. This was particularly undesirable on washdays, since staff residences were clustered around the college and up and down the valley. The problem had an easy solution--since when a 54-tube Hagan Aerostatic Dust Collector was installed, the flyash menace to clean clothes simply ceased. In fact, one resident said--for the first time in many years, we had white snow this winter. Everyone is pleased, especially the college, since an electrostatic collector doing the same job would have cost 8 to 10 times as much as the Hagan unit. The principle of Selective Particle Acceleration, exclusive with Hagan, is the reason why Hagan dust collectors obtain remarkably high efficiencies, even with such finely divided dusts as fly ash. (Item G-2)

DUAL CONTROLS IMPROVE BLAST FURNACE EFFICIENCY

A modernization program for a blast furnace included the installation of a Hagan blast furnace blower control system. Designed to maintain a steady flow of blast air, the system has helped improve overall performance, and lower operating costs. Such results are to be expected from Hagan systems, but this particular installation differs from the average in one major aspect. The usual control panel is installed in the blower room, but an additional station is located in the cast house. This allows the cast house operator to take over direct control when desirable, and maintain the exact conditions required without the delay caused by signaling between cast house and blower room. This dual system has added much to the flexibility of the system and is credited with raising production. (Item G-3)

METERING CHEMICAL FEEDS?--THIS METER IS ACCURATE OVER WIDE TURNDOWN

At a large utility a Hagan Ring Balance meter was to be used to control the feed of lime and soda ash to their hot process lime softener. Because of extreme variations in flow, two line sizes were used in the meter run so that they could switch from a large to a small line when plant make-up requirements approached minimum rates. However, the small line proved to be inadequate. Rather than change lines, plant personnel decided to try operating over the full load range on the large line. The accuracy of the feed was checked by the plant chemist who would analyze the treated water to within 1 PPM. Chemicals used were also compared to the total volume of raw water. Both of these checks showed that the Hagan meter was holding the required chemical feed proportions within 1 PPM, even though loads frequently fell well below 10% of chart. (Item G-4)

HAGAN CHEMICALS & CONTROLS, INC.

Hagan Building, Room 705, Pittsburgh 30, Pennsylvania
In Canada: Hagan Corporation (Canada) Limited, Toronto
European Division: Via Flumendosa No. 13, Milano, Italy

If you would like more information on any of the above items, check the appropriate box below.

☐ Item G-1 ☐ Item G-2 ☐ Item G-3 ☐ Item G-4

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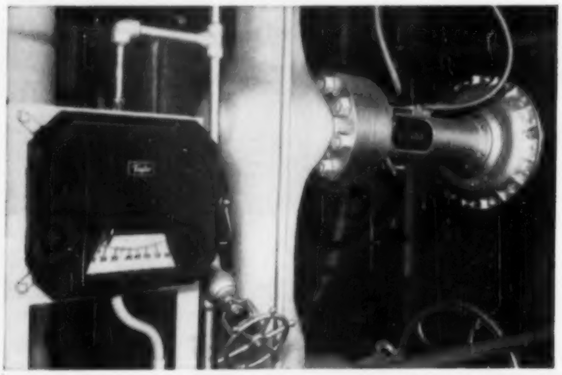
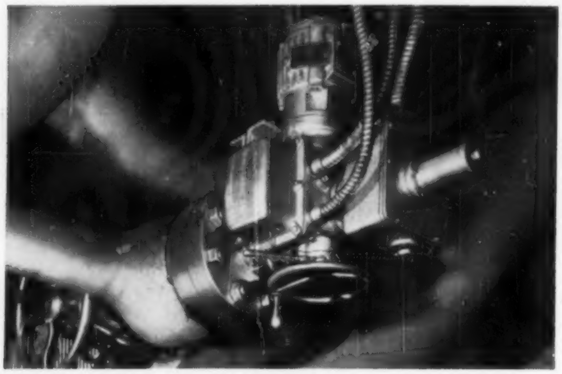
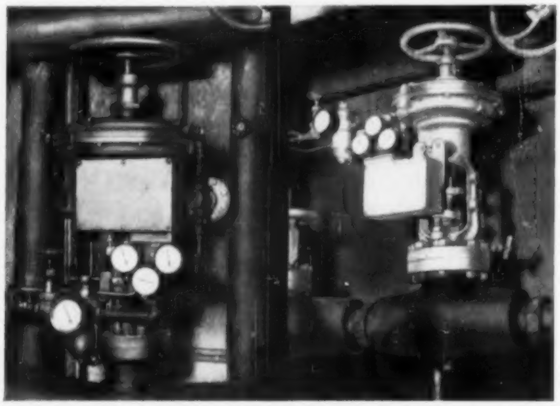
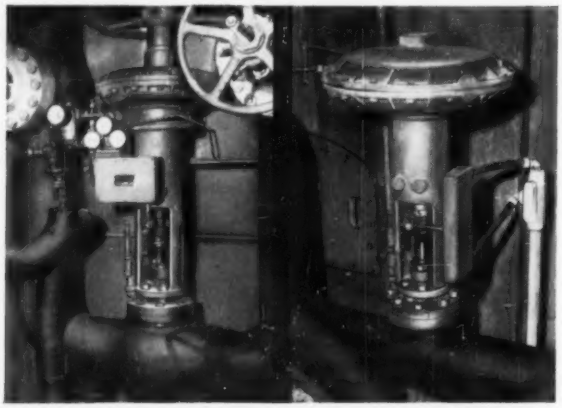




At a key eastern power station Copes-Vulcan valves protect three boiler feed pumps in a recirculation control system (left), and a motor operated valve is used in the feedwater by-pass line (right).



Valves used in modern combustion control system. One diaphragm-operated valve is used as a single-seated fuel return control valve (left) while another controls the speed of the turbine driving the forced-draft fan (right).



Efficient feedwater-flow control system uses a Type CV-D valve equipped with positioner, air lock, and emergency handwheel operator (left). Another diaphragm-operated valve trips automatically if fuel-oil line pressure drops below a safe limit (right).

Copes-Vulcan Regulator Valves bring precision control to exacting jobs

Designed for superior accuracy and long range dependability, Copes-Vulcan valves establish new standards of efficiency for pressure, temperature, flow, and level control.

To assure trouble-free performance, Copes-Vulcan custom designs each valve to suit your most rigid control requirements. The kind of fluid—its flow, pressure, and temperature—are all studied before a recommendation is made. Port area and style are selected on the basis of careful research.

The Copes-Vulcan line includes the following valves:

Diaphragm valves (Type CV-D) provide greater versatility . . . have excellent rangeability . . . may be direct or reverse acting.

Piston-type valves (Type CV-P) offer simplicity of design . . . ideal where valve-operating force must be unusually high, where positioning must be precise.

Nuclear valves for ships, atomic plants, and test reactors. Supplying valves for these advanced projects offers proof of the acceptance of Copes-Vulcan's skill and integrity.

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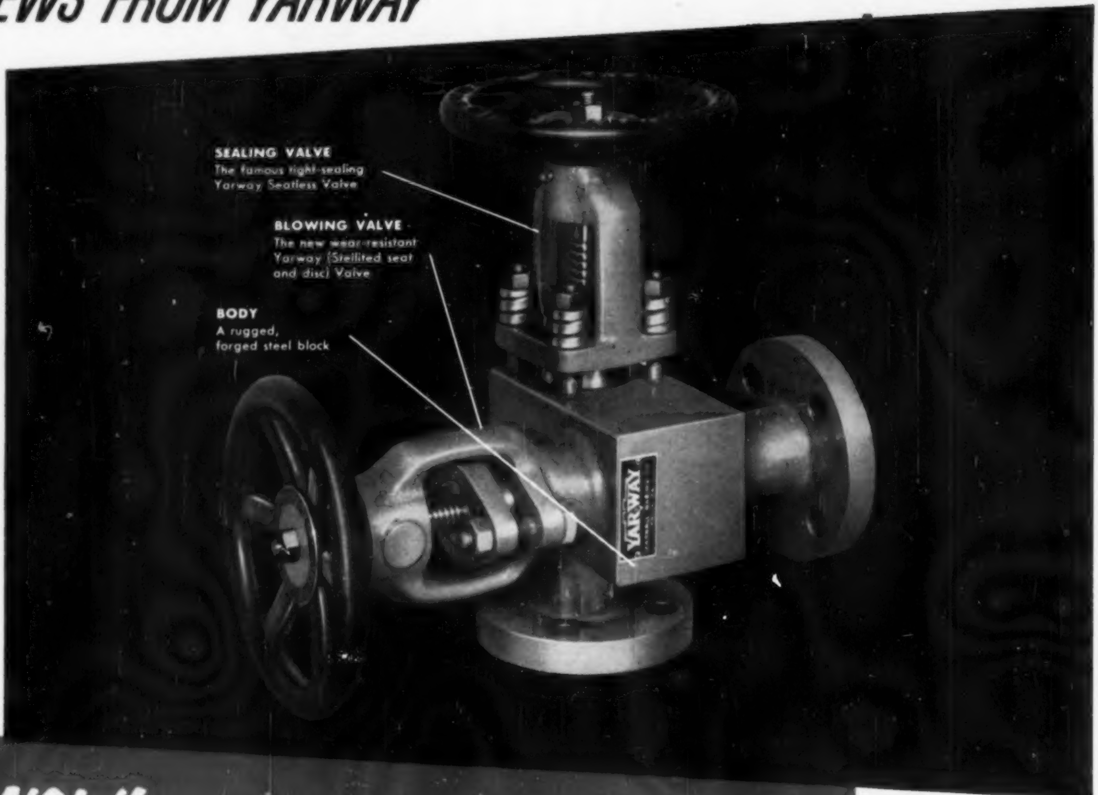
NEWS FROM YARWAY



NOW! A NEW YARWAY UNIT TANDEM BLOW-OFF VALVE FOR MEDIUM PRESSURE BOILERS

There's a new star in the Yarway Blow-Off Valve line.

For years rugged Yarway Unit Tandem Blow-Off Valves have been standard equipment on most high pressure boilers. In fact, more than 80% of high pressure plants use Yarways.

Now a *new design* Unit Tandem is offered for *medium pressure boilers to 665 WSP*. Streamlined, lighter in weight, easy to operate, tight sealing and long wearing—this valve brings premium quality Yarway Unit Tandem dependability to the medium pressure field—*at a competitive price!*

Important features, like the nitralloy plunger in the sealing valve and integral stellite seat and disc in the blowing valve, make this your best buy for blow-off service.

Order Yarway Unit Tandems for your present boilers—or specify them on new boilers.

For full details write for Yarway Bulletin B-435, Supplement A.

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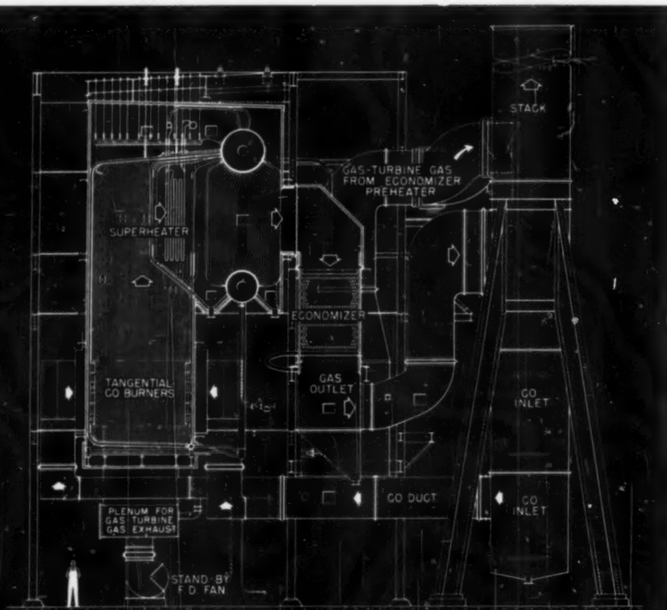
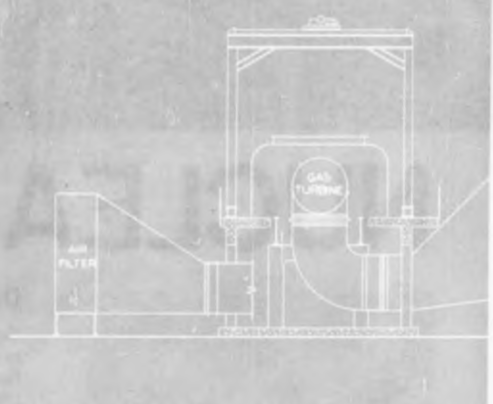
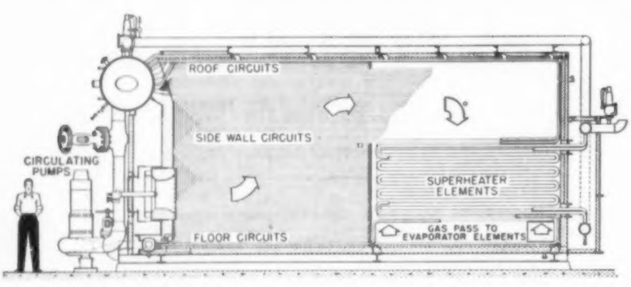


For refineries

C-E Vertical Unit Boiler, Type VU-40 CO — tangentially fired boilers to efficiently utilize energy potential in hard-to-burn waste catalyst regenerator gas. Illustrated is an installation at a Gulf Coast refinery. It combines a catalyst regenerator, two gas turbine-driven compressors, two CO boilers, and separate turbine exhaust-gas feedwater heaters located between the boilers. Available in a wide range of sizes for any quantity of catalyst regenerator gas and for any steam capacity, CO Boilers by C-E have been in service more than three years.

Special boilers for special





For diverse industrials

C-E Package Boiler, Type PCC—new, completely shop-assembled, high performance, Controlled Circulation steam generator. Now in service with capacities to 120,000 lb/hr, it is available with temperatures to 900 F. and pressures to 1,000 psi (or higher if desired). This boiler is especially suitable where maximum capacity, temperature, and pressure are required, yet space is limited. Offers easy handling of rapid load swings and high quality steam production. PCC's in service include the world's highest capacity, highest pressure, and highest temperature package boilers.

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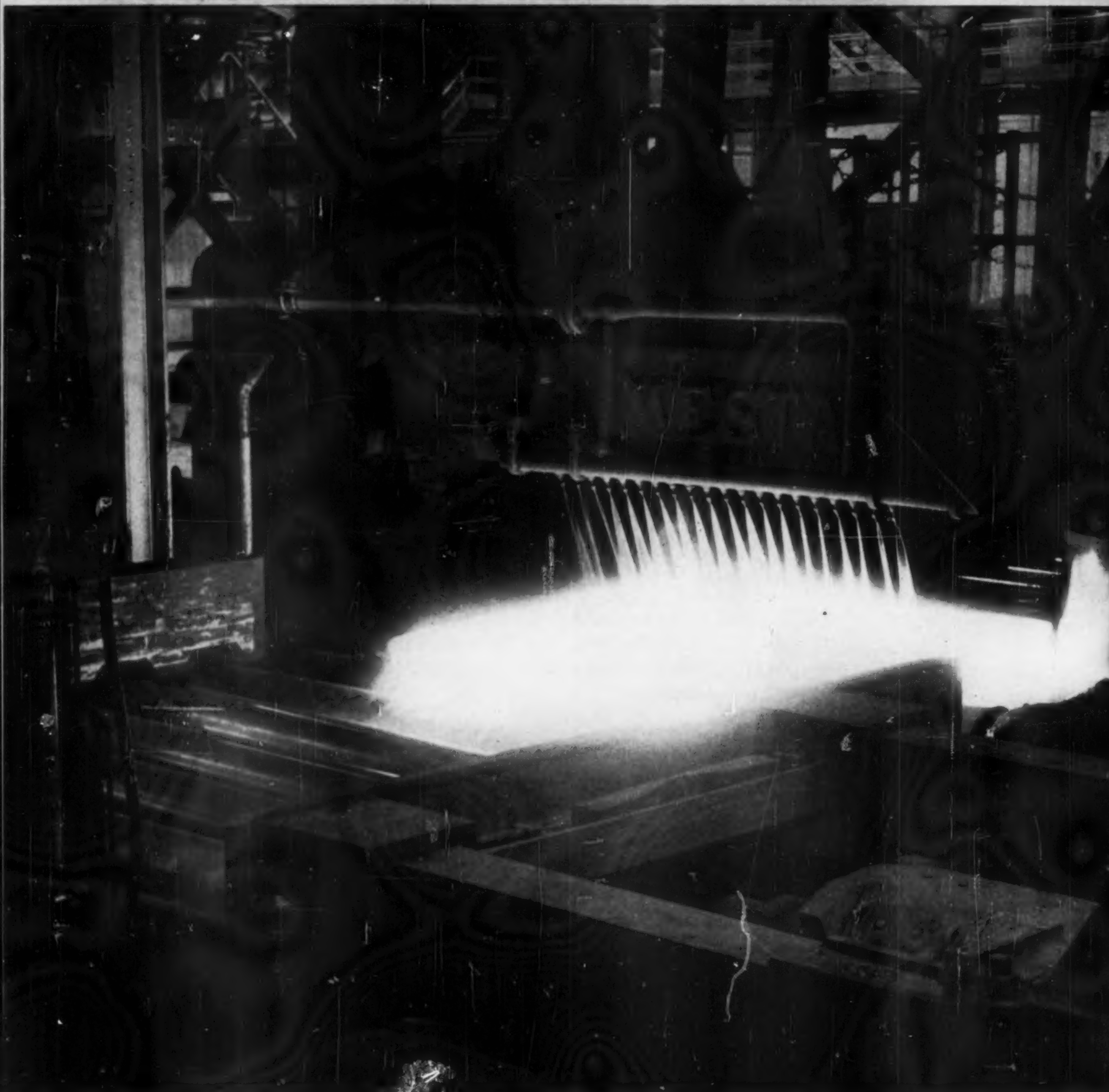
for high-pressure

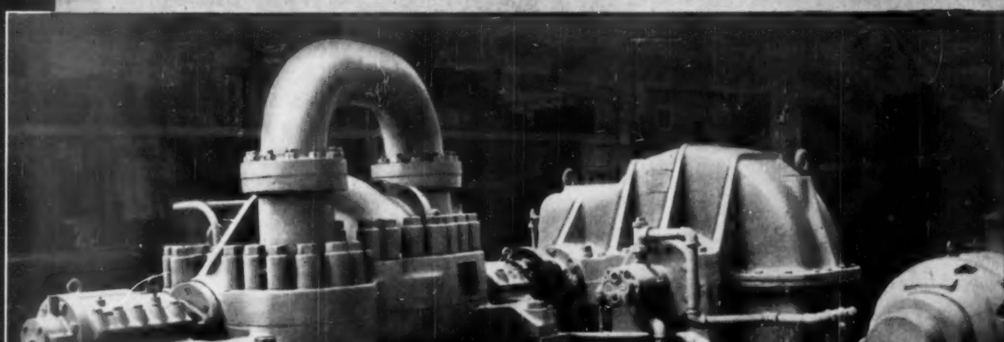


descaling at Lukens Steel

Latest successful technique of high-pressure descaling is now being performed in this modern steelmaking facility designed by Mesta Machine Co.

The initial high-pressure descaling operation uses De Laval split-case multi-stage pumps as shown in the photograph below. Each pump supplies cold water at 1000 gpm and 1600 psig. Electric motors rated at 1750 hp drive the pumps through speed increasers which raise the speed from 1200 rpm to 4250 rpm.

De Laval pumps also serve Lukens on a 1200 psig descaling system in another section of the Coatesville, Pa. mill.



One of several arrangements available for descaling service at pressures of 1000-1200-1600 psig and capacities to 2200 gpm.

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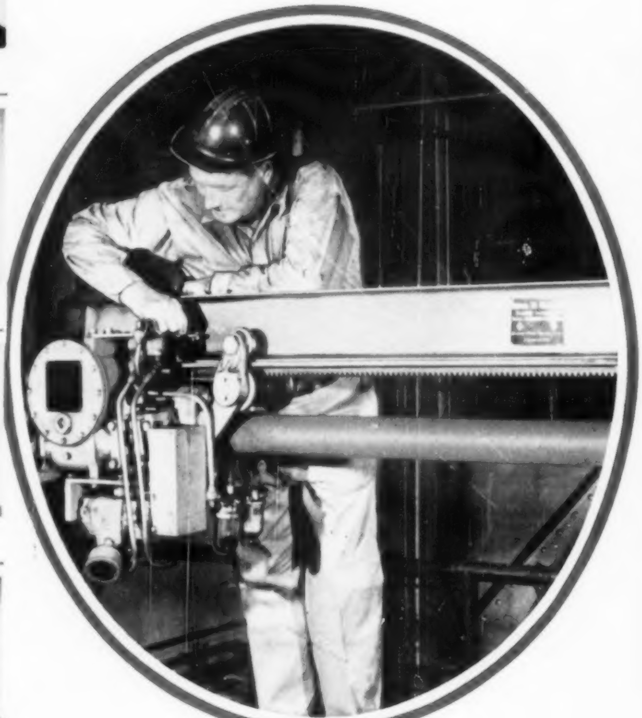

Diamond Service Engineer making an adjustment on a Model IK Long Retracting Blower to assure maximum cleaning efficiency. Diamond Service is effective preventive maintenance.


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A unique field service organization dedicated to giving you

Better Boiler Cleaning At Lower Cost

The principal duty of these 31 full time, factory trained field service engineers is to insure that Diamond Blowers operate correctly to give you the best boiler cleaning possible and at minimum cost. They are cleaning experts who inspect and adjust Diamond Blowers in stationary (and marine) water tube boilers. This inspection service is rendered regularly . . . unsolicited and without charge.

There is nothing else quite like it in the power industry, and it saves the user of Diamond Blowers money two ways: First, these men often are able to detect potential trouble before it becomes serious or costly . . . preventive maintenance that keeps repair costs down. Second, by seeing that blowers are in good repair and adjustment . . . instructing operators in correct operation and care . . . and by recommending the most efficient and economical blowing schedules, they assure cleaner boilers at lower cost. Boiler efficiency is maintained . . . blowing costs kept down.

This is one of many important plus values you get with Diamond Blowers and Blower Systems.

Diamond Service Engineer showing operator how his flue gas temperature drops when he uses his blowers correctly and regularly.

Diamond Service Engineer makes internal inspection to check cleaning effectiveness of the blowers.

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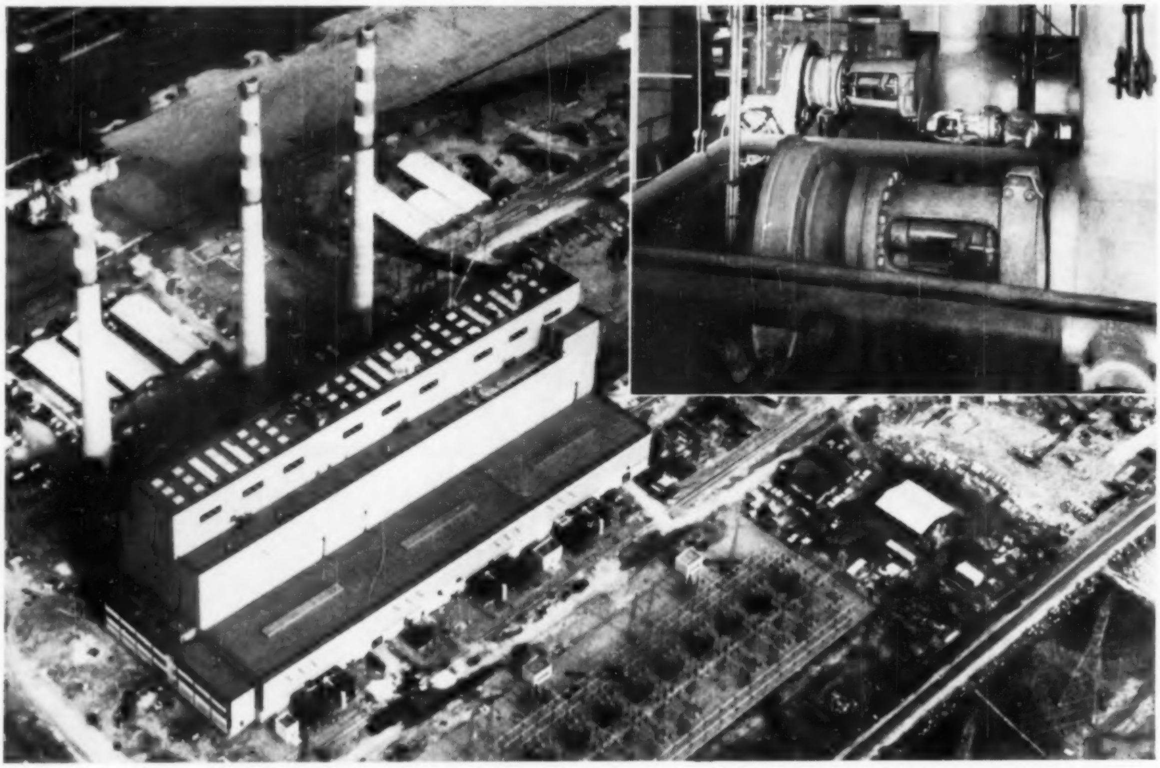


Thomas H. Allen Generating Station—Memphis Light, Gas & Water Division—City of Memphis, Tenn.
Burns & Roe, Consulting Engineers. Generating Capacity: 862,500 kw. Insert shows some of the 8000 Crane valves installed in plant.

Crane builds giant pressure-seal bonnet valves for giant Memphis power plant

The Thomas H. Allen Electric Generating Station, pride of Memphis, Tenn., is the largest municipal power plant ever authorized at one time. This huge, 121-million-dollar project, in full operation, has an output capacity of 862,500 kw.

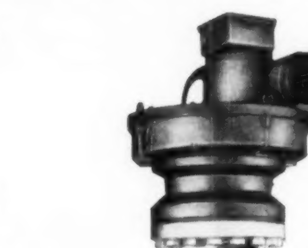
Piping plans for this immense plant called for 24 16-inch, motor-operated high-pressure/temperature angle valves—*largest valves of this type ever to be made*. They were for service on the inlet and outlet ends of 12 high-pressure, multiple-pass feed-water heaters.

Crane built all 24 valves—in pressure-seal bonnet design. These valves can handle a flow of two million pounds per hour at 585° F. and are designed for tight shutoff at 2840 psi under the disc. Special motor-operators had to be developed to provide the 500,000-pound thrust required for closing.

8000 valves—mostly Crane

In addition to supplying these 24 specially made angle valves, Crane also furnished most of the approximately 8000 other valves used on the job—carbon steel, alloy steel, iron and bronze.

Who but Crane has the modern facilities—in metallurgy, casting, inspecting, testing and other manufacturing procedures—for producing quality valves in *any* size, to *any* specifications, in *any* quantity on *schedule!* For details, consult your Crane Representative.



One of the 24 16-inch, motor-operated pressure-seal bonnet angle valves made specially by Crane. Stands 11 feet high . . . weighs 11,000 pounds.

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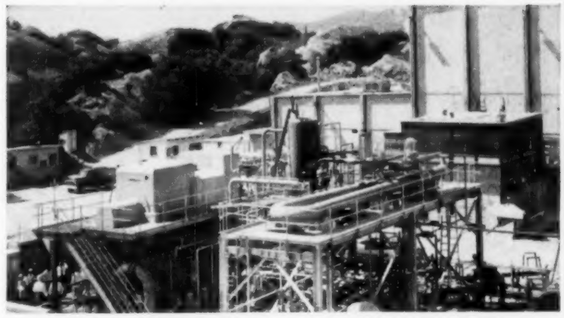
System Cleaning, Start-Up and Analytical Techniques for Unique Steam Generator Heated by Sodium Reactor



Known as the Sodium Reactor Experiment conducted for the Atomic Energy Commission by Atomics International, and located in the hills thirty miles northwest of Los Angeles, this installation is full of "firsts" and "never befores." Prominent among them is the Southern California Edison Company's steam electric plant including a once-through superheated steam generator, producing 7,500 EKW from 77,500 lbs. of steam per hour at 620 p.s.i.a., 825°F.

Heat is transferred from the nuclear reactor to the steam generator via two separate liquid sodium circuits. The two circuits are separated by an intermediate heat exchanger to avoid radioactivity in the steam generator circuit. Liquid sodium reaches the steam generator at 900°F; returns to the primary exchanger at 440°F.

Water/steam tubes of the generator are each 80 feet long, curved into a U-shaped bundle as shown below, and in the photo at upper right. These tubes are enclosed in concentric tubing containing mercury to prevent any possible contact between the liquid sodium and water or steam (diagram at right).

The entire steam generator is built as a single unit, so repair or internal difficulties caused by deposits or corrosion would create major down-time and maintenance problems . . . which is the point Nalco Consulting Services enter the picture.

Severe Basic Requirements

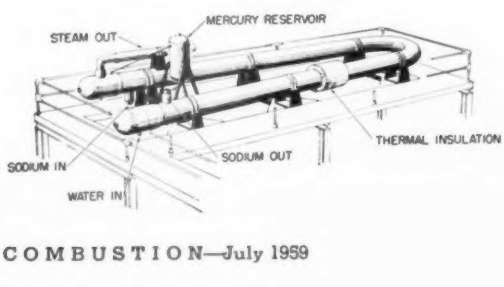
Nalco consultants, working closely with Southern California Edison engineers, determined that permissible dissolved solids in the boiler water should not exceed 0.5 p.p.m., with the following operating range: .001-.003 ppm O_2; .01 ppm Fe; .01 ppm Cu; .02 ppm Cl. Demineralization is utilized for feedwater preparation, and part of the condensate can be passed through the demineralizer if contamination occurs.

The job for Nalco was to set up proper analytical control procedures and methods to assure operation well within the permissible operating ranges.

System Cleaning

Prior to start-up, Nalco set up a complete, step-by-step procedure for cleaning the steam system. As noted above, the single-unit steam generator interior is not only inaccessible for normal inspections or maintenance, but also had to be cleaned for initial operation "by remote control." Testing procedures and analytical methods used as recommended by Nalco at this stage were critical to subsequent successful operation. They worked.

STEAM GENERATOR

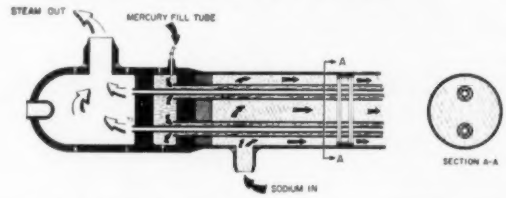


Information Programming

Setting up a sensible information program for this unique installation produced problems hinging on: "What do we *need* to know?" and "What analytical procedures can be used to assure adequate information and accuracy without excessive time and complexity?"

Dealing in impurity limits which would normally be considered "below zero," and with the possibility that entirely new problems could develop in operation, the information and analytical procedures devised by the Southern California Edison-Nalco team are producing data on performance and internal conditions which are accurate, adequate guides to successful operation.

HEAT EXCHANGER CUTAWAY



It is unlikely that your project or problem directly parallels the Sodium Reactor Experiment. However, Nalco's willingness to tackle new areas of research and development, using an unsurpassed background of experience and abilities in specialized chemical technology, may be very valuable to you. Nalco Bulletin D1 describes Nalco Consulting Services and Contract Research in detail. Your copy will be sent promptly at your request.

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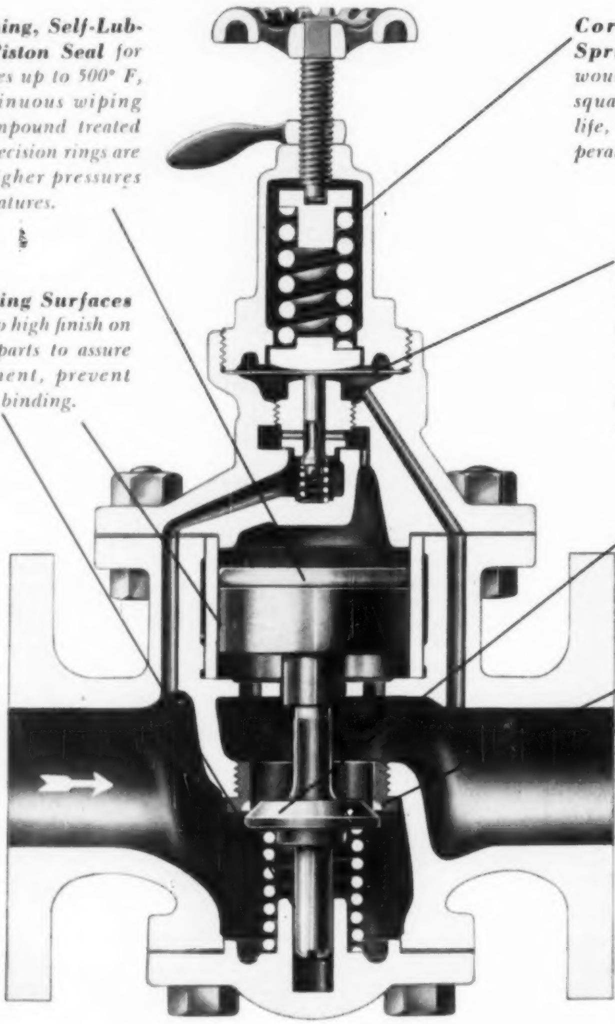


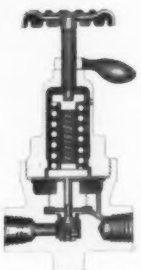
Cutaway of Leslie internal pilot, piston operated reducing valve class LY, shows typical Leslie quality construction features. Throughout the Leslie line, features like these and others presented on the next page are your assurance of lower operating costs and long life performance. They are based on over 50 years of leadership in designing and manufacturing quality regulators.

Internal pilot piston operated reducing valves are available for steam services, up to 2500 lbs., ASA, reduced pressure ranges to 1400 psi. Sizes ½ to 6". Cast iron, bronze, steel or alloy steel construction.

LC-9

IN LESLIE'S REDUCING VALVES AND REGULATORS

LESLIE SMALL FLOW REDUCING VALVES



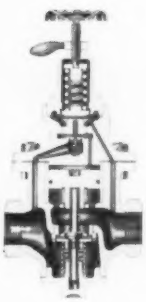
Leslie small flow reducing valves are used in pilot plant operations, plastic molding presses, laboratory units, gland sealing, steam sterilization and atomizer units and wherever control of small flows of steam, air, gas or non-corrosive liquids are a problem.

These ½" valves feature simple, direct operated design with screwed or bolted adjusting spring assembly for easy access to the internal parts. No stuffing boxes or fussy seals.

PRESSURE-TEMPERATURE RANGES

BODY MATERIALS AND CONSTRUCTION	CLASS	MAX. INLET PRESSURE PSI STEAM	MAX. INLET PRESSURE PSI COLD LIQUID AIR OR GAS	MAX. TEMP. °F.	MIN. PRESS. DROP PSI	REDUCED PRESS. RANGE PSI
BRONZE Screwed Bonnet	LCA	–	400	150	10	5-285
	LCB LCC LCD	300	400	550	10	10-285
	LCLA	–	400	150	10	2-35
	LCLB LCLC LCLD	300	400	550	10	2-35
STEEL Thru-bolted Bonnet	LCL(B)S LCL(C)S LCL(D)S	600	1000	750	10	25-400 10-50

LESLIE REDUCING VALVES FOR AIR OR GAS SERVICE



Leslie internal pilot, piston operated reducing valves offer a combination of accurate regulation and low maintenance service, and are used for accurate control of air or gas with inlet pressures up to 400 psi at 150° F.

Accuracy of regulation is comparable to instrument control with full flow for equivalent pipe size. Valves feature 99% accuracy of regulation at rated capacity.

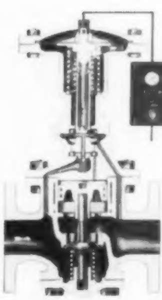
Positive, bubble tight shut-off is provided by resilient, single seated valve disc. Fully guided main valve, stainless steel diaphragm and non-corroding internal springs assure long, trouble-free operation.

PRESSURE RANGES AND CONSTRUCTION

CLASS	SIZE (Inches)	MAXIMUM INLET PRESSURE & TEMP.	REDUCED PRESSURE RANGE-PSI MIN.	REDUCED PRESSURE RANGE-PSI MAX.	BODY MAT'L.	END CONNECTIONS
LA-5 LAE-5	½-4	25-400 psi 150° F max.	5*	285	Bronze	½-2" 300 lb. screwed ½-4", 150 & 300 lb. MSS flanged
LAK LAEK		25-400 psi 150° F			Cast Iron	½-2" 250 lb. screwed 1½-3" 250 lb. ASA flanged
		25-175 psi 150° F max.				1½-4" 125 lb. ASA flanged

*5% of inlet pressure over 100 psi

REMOTELY ADJUSTED REDUCING VALVES



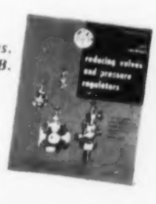
Operating characteristics of Leslie remotely adjusted reducing valves are identical to manually adjusted types. The remotely adjusted reducing valve is adjusted to the desired pressure setting by air pressure from an air loading device. The constant loading force on the upper diaphragm opens the pilot valve and is balanced by a constant reduced pressure proportional to the loading force.

The air loading panel eliminates hazardous or inconvenient adjustments and provides fast means of readjusting pressure to meet changing requirements.

REMOTELY ADJUSTED REGULATING VALVES

TYPE	SIZES AVAILABLE (Inches)	BODY MATERIALS AVAILABLE	INLET PRESSURE RANGES (PSI)	MAXIMUM REDUCED PRESS (PSI)
Small flow, internal pilot actuated, diaphragm operated	¼, ⅜, ½	Bronze	20-300 psi 550° F steam 20-400 psi 150° F air	175
Internal pilot actuated, piston operated	½ - 6	Cast Iron Bronze Cast Steel	25 psi up to 600 psi, 750° F	175
Internal pilot actuated, piston operated for high pressure service	½ - 3	Cast Steel and Alloy Steels	300 psi up to 3000 psi	700

For sizing and capacity data on this Leslie line of valves, contact your Leslie engineer or write for Bulletin 5302B.



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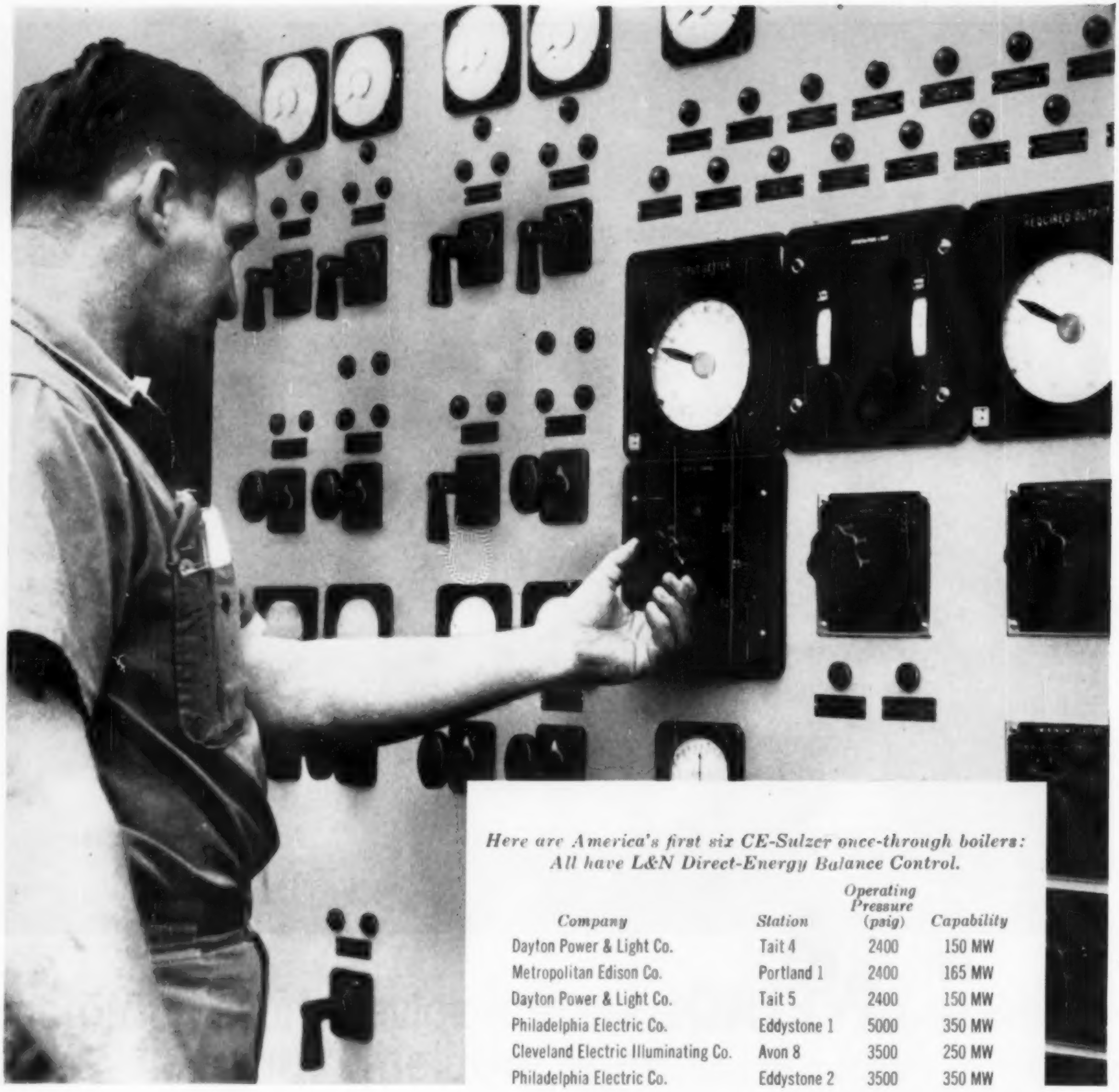

Here are America's first six CE-Sulzer once-through boilers: All have L&N Direct-Energy Balance Control.

Company	*Station*	*Operating Pressure (psig)*	*Capability*
Dayton Power & Light Co.	Tait 4	2400	150 MW
Metropolitan Edison Co.	Portland 1	2400	165 MW
Dayton Power & Light Co.	Tait 5	2400	150 MW
Philadelphia Electric Co.	Eddystone 1	5000	350 MW
Cleveland Electric Illuminating Co.	Avon 8	3500	250 MW
Philadelphia Electric Co.	Eddystone 2	3500	350 MW

Once-through boiler and turbine operate as a unit with new L&N Direct Energy Balance Control

Here at the Frank M. Tait Station of Dayton Power & Light Co., America's first and third CE-Sulzer once-through boilers are in operation. Working at subcritical pressures, they employ a major advance in combustion control—Direct-Energy Balance.

L&N developed this D.E.B. control for once-through boilers to provide closer regulation. The boiler and turbine are operated as a unit, keeping the generator output within the capabilities of the equipment in service. In the picture above, an operator at Tait is setting the desired rate of generation change directly. Calibrated in MW/min, this control changes output at the rate he sets, so that the boiler and turbine will respond as an integrated unit.

The Direct-Energy Balance method has been extensively field tested and subjected to simulation studies at our computer facility. For further information, contact your nearby Field Office, or write for Reprint 463(8) to 4972 Stenton Ave., Phila. 44, Pa.

Direct-Energy Balance Control . . . engineered to power plant standards by **LEEDS & NORTHRUP**
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COMBUSTION

Editorial

Are Banquets Obsolete?

The ingredients of a banquet are people, food, drinks, entertainment—and speeches. No major engineering meeting appears to be self-respecting unless it includes one or more festive occasions to make up this concoction.

Not long ago we attended a banquet and sadly observed that a respected colleague with a gift for stimulating conversation was sound asleep. The speaker was vibrant but the editor was somnolent. A few minutes earlier, the roles were reversed, for the speaker was nervously partaking food and suffering through pre-speech jitters, while the editor was enjoying the luncheon and entertaining his associates.

This puzzled us for a while. Then this thought hit: the distinguished executive was a speaker only to the extent of contributing his voice and his physical presence! Someone else had written the speech for him; now he was droning it forth at the measured pace of an automatic prompting machine. Why should the audience sit passively by and have such artificial second-hand sounds inflicted upon it?

Our colleague did the right thing. He glanced over the speech manuscript in five minutes and slept the remaining twenty-five needed for oral presentation. Perhaps he was disrespectful to his fellow editors around the banquet table, but was he any more so than the speaker who proved to 1500 people that if Johnny can't read in grade school, his grandfather can scarcely do much better fifty years later?

What are the solutions? Abolish banquets—not very likely. Eliminate the after-dinner speaker—not unless you can abolish host committees, and then how are you going to have meetings? Pass out copies of the speech to all present—this might deter some timid readers. Tape record the speech in advance—this has some interesting possibilities.

We suspect that engineering society banquets will always be with us. And we know that big names will always attract a large attendance. We are not sure that banquets are obsolete, but we have all too much evidence that the vast majority are boring.

By V. Z. CARACRISTI† and H. D. MUMPER‡
Combustion Engineering, Inc.

Combustion of Crushed, Dried Texas Lignite and Char in Steam-Power Boilers*

Process fuels of a hot, highly reactive nature may result from industry's attempts to achieve low temperature carbonization of coals and lignites. The authors describe how the problems of handling, feeding and transporting these process fuels were met in one instance and the experience record being established.

THE Aluminum Company of America in 1949 faced a production capacity problem. The available undeveloped hydroelectric power sites in this country were dwindling, and it appeared that inevitably steam-electric power must be used if aluminum capacity were to keep pace with the expanding postwar market. The onset of the Korean war made aluminum expansion essential to the national defense, and as a result of the extensive development work undertaken by the Texas Power and Light Company and the USBM to adapt the Parry carbonization process to Texas lignite, and through the efforts of Dr. V. F. Parry and others, the Aluminum Company in 1950 made a decision to construct a primary aluminum smelter on the site of one of the Texas lignite fields (1).[1] A 300-megawatt steam power plant was to supply the smelter, using carbonized lignite as the basic fuel.

The carbonizing process was planned for two stages of development, the first stage consisting of a drying operation to reduce moisture content from the 28 to 35 per cent of the raw lignite to approximately 3.6 per cent in the dried product. The second stage would carbonize the dried lignite to extract low-temperature tars, while producing lignite char as the power-plant fuel.

The decision to proceed in two distinct steps resulted from the need to get the power plant and smelter into immediate operation while carbonizing operations could be developed further and gradually introduced as a tar market appeared. Combustion Engineering, Inc., contracted to furnish three boilers for burning either crushed dried lignite or lignite char with steam conditions as outlined later.

The fuels to be used were unique. The initial fuel was specified as dried Texas lignite of 3.6 per cent moisture, crushed to 0 per cent plus 8 mesh and 18 per cent minus 200 mesh, with a volatile content of 39.5 per cent and a heating value of 10,420 Btu per lb, delivered at the fuel silo at 200 F. Eventually when carbonization was in full operation, the fuel would be lignite char at zero moisture content, with a size consist of 0 per cent plus 16 mesh (U. S. Std.), and 36 per cent minus 200 mesh, a volatile content of 25.5 per cent and a heating value of 11,030 Btu per lb, delivered at the fuel silo at 900 F. The size consist of these fuels is shown in Fig. 1. Fuel analyses are given in Table I.

The characteristic of lignite fuel producing size degradation upon heating permitted the basic concept of suspension burning in a conventional slagging-type furnace. The development of this steam-generating unit was primarily centered around handling a product which was originally coarse ground and dried or carbonized to permit degradation to a relatively small size. The high reaction rate of the dried lignite and lignite char, its relatively small particle size and the possibility of further size

* Presented at the Semi-Annual Meeting, ASME, St. Louis, Mo., June 14–18, 1959.
† Assistant Chemical Engineer.
‡ Engineering Specialist.
[1] Numbers in parentheses designate References at the end of the paper.

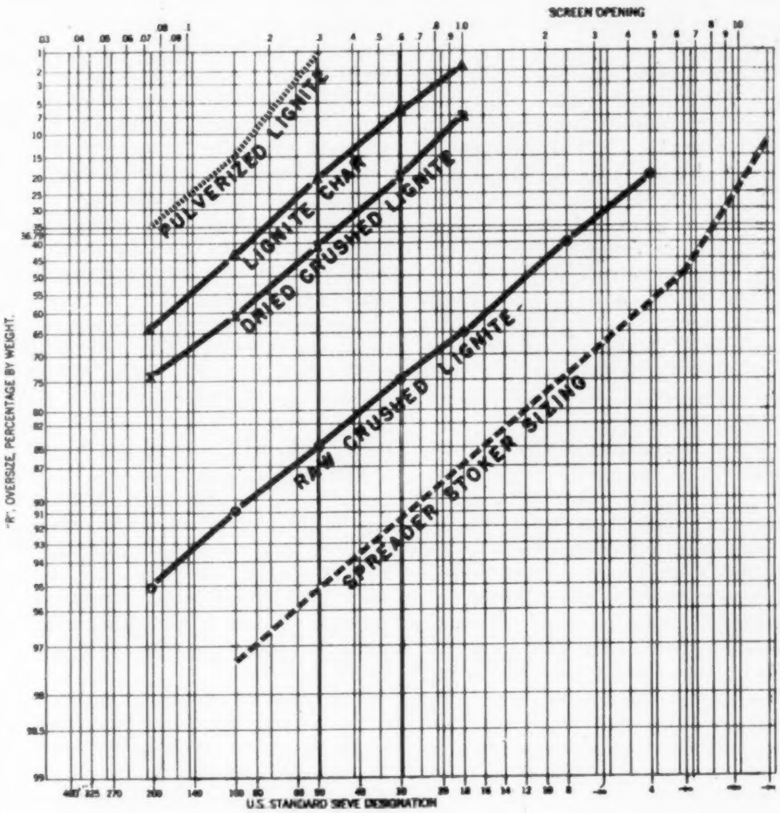

Fig. 1—Comparison of the size range of the fuels under discussion can be obtained from the above plot made on the U. S. Bureau of Mines graphical form for representing distribution of sizes of broken coal. Note fuel handled is coarser than pulverized lignite and finer than spreader stoker

degradation on entering the combustion zone permitted the elimination of the conventional pulverizer in the fuel-burning system.

The elimination of the pulverizers and the handling of the hot dried or carbonized highly reactive fuel are the unique features of this steam-generating installation. The nature and character of the ash deposit on furnace heat-absorbing surface and convection superheater surface were quite unexpected. This introduced an unforeseen problem which can be associated with the nature of the ash in the raw lignite. This ash-deposit problem is indicative of what can be expected with lignite as a fuel on a high-pressure, high-temperature, steam-generating unit. It was possible on these units to establish parameters for handling this ash-deposit problem which should avoid these difficulties on future lignite-fired units.

The complex problems of handling, feeding and transporting hot highly reactive solid fuels in coordination with the requirements of the steam-generating unit were completely new. The solution of these problems represented considerable effort, time and expense on the part of the supplier of the steam-generating unit. It is significant that the solution of these problems required data and tests that are applicable to the handling of many similar process fuels that may be available in the near future.

The Initial Design

The three boilers supplied by Combustion Engineering, Inc., for this project are rated at 800,000 lb per hr steam flow maximum continuous capacity at 1550 psig and 1005 F main steam conditions with reheat to 1005 F. The 8-hr peak capacity is 880,000 lb per hr main steam flow and 764,000 lb per hr reheat flow. Fig. 2 is a sectional side elevation of the original unit design. These units drive three 100/80-megawatt General Electric turbine-generators with a capacity of 120 megawatts at 30 psig hydrogen pressure.

There are no pulverizers. The stored fuel is injected into the furnace through tangential burners which produce a large turbulent flame of the smaller particles in

TABLE I—FUEL CHEMICAL ANALYSES

	Original Specification		Range of Actual Analyses	
	Dried Lignite	Lignite Char	Dried Lignite	
Carbon	59.6	64.1	59.0	61.0
Hydrogen	3.7	3.2	3.2	4.5
Oxygen	18.0	9.4	11.2	15.3
Nitrogen	1.2	1.4	1.3	
Sulfur	1.6	1.7	1.6	2.0
Ash	15.9	20.2	14.5	18.1
Moisture	3.6	0.0	1.8	3.1
H.H.V.	10,420	11,030	9930	10,900
Volatile matter	39.5	25.5	41.4	42.7
Ash fusion range °F				
T.I.D.	...	...	2080	2240
A.S.T.	2100	2100	2130	2290
A.F.T.	...	...	2140	2390

	Fuel Size Analysis		
	Crushed Raw Lignite	Crushed Dried Lignite	Lignite Char
Plus 8 mesh	40%	1.9%	0%
Plus 18	65	7.	1.5
Plus 30	75	20.	7.
Plus 50	85	41.	21.
Plus 100	91	61.	43.
Plus 200	95	82.	64.
Minus 200	5	18.	36.

the furnace cavity, while larger fuel particles are spun out by centrifugal action to be trapped and burned in the molten slag coating the furnace walls in the burner band. Molten slag is continuously discharged through the taphole into a water-filled quench tank.

The furnace walls are completely water-cooled by 3-in. tubes on $3^1/_{16}$-in. centers. To prevent metal corrosion in the burner band, as experienced in slag-tap furnaces of the early 1940's, the lower 30 ft of the furnace tubes are aluminized by hot dipping, a technique that has been successful in preventing such corrosion in slag-tap furnaces since 1946. The floor consisted of 3-in. tubes on $6^1/_4$-in. centers covered by bolted-on cast-iron floorblocks with chrome plastic refractory above the blocks. The superheater and reheater are in two sections, each having a high-temperature pendant in the furnace outlet, the reheater following the superheater, and a low-temperature section of the horizontal-tube type in the rear downward gas pass. The low-temperature reheater and low-temperature superheater are in parallel gas paths. Economizer surface extends through both gas paths and is followed by dampers which proportion the gas flow between the reheater and superheater gas paths. The unit design includes two Ljungstrom regenerative air preheaters and a Western multiclone dust collector.

Two gas-recirculation fans were provided to recycle flue gas from the economizer-outlet gas duct under the proportioning dampers to tangential injection ports above the windbox in each corner. The combination of gas recirculation and gas proportioning dampers was intended to control main steam and reheat steam temperatures at 1005 F over a load range from 500,000 lb per hr main steam flow to 880,000 lb per hr.

The fuel was received from pneumatic transport lines utilizing air or inert-gas medium for dried lignite and lignite char, respectively. Separation of the suspended solid fuel was accomplished by three 6-ft-diam single cyclones per unit supported above a 150-ton-capacity cylindrical steel fuel-storage silo designed as a pressure vessel for 50 psig internal pressure.

The separated fuel in each cyclone was dropped through a 10-in. opening into the fuel silo, Fig. 3, and the transport fluid was discharged through a 16-in. exhaust line into a pressurized 45-in. line carrying flue gas to the boiler-burner transport plenum. To protect the fuel silo against the intrusion of transport air through the cyclone necks with the fuel, a small line carried pressurized flue gas from the boiler fuel-transport gas line ahead of the cyclone exhaust into the top of the fuel silo. This inerting gas crossed the silo above the fuel surface and flowed back into the boiler-fuel transport gas line through an aspirating annular opening in the transport gas line which passed vertically downward through the center line of the fuel silo. The vertical downward leg of the transport gas line ended in the transport gas plenum 50 ft below the fuel silo. The pressure drop of two turns in the gas line plus the aspirating effect of the annular opening in the upper portion of the fuel silo provided enough pressure drop to induce a flow of inerting flue gas through the silo as described above.

The fuel-silo design included three large explosion rupture disks at the top, three smaller rupture disks at the top of the exhaust stacks of the three fuel-separating cyclones, and an additional large rupture disk at the highest point in the 45-in. fuel-transport line above the silo. The granular-fuel flows from the storage silo through six downspouts to six rotary pocket-roll feeders which discharge fuel through splitter breechings into twelve fuel lines.

The boiler-fuel transport system as designed consisted of two primary gas fans which delivered economizer-outlet flue gas to the cyclone-air exhausts, from which point the mixture of boiler flue gas and process transport air containing 12 per cent oxygen went to the boiler-fuel transport gas plenum and became the medium for fuel transport to the burners, Fig. 3. Six large-diameter lines carry the gas from the plenum chamber to splitters supplying twelve 12-in. burner-transport lines. At this point the six pocket-roll feeders drop the fuel onto pickup lattices in the twelve burner lines where it is entrained by the primary gas-air mixture and transported in suspension to the twelve tangential burners. Each pair of fuel

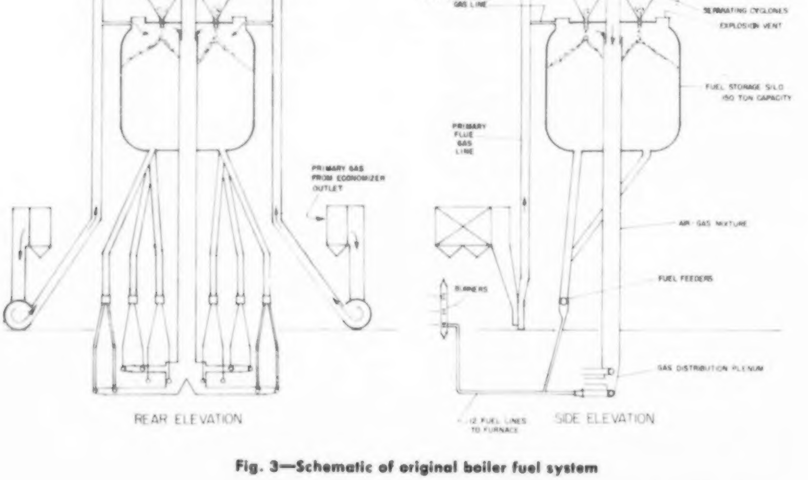

Fig. 3—Schematic of original boiler fuel system

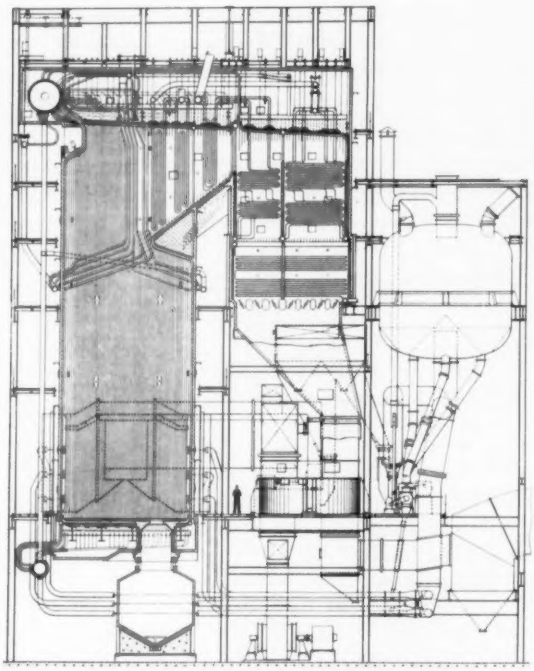

Fig. 2—Sectional side elevation original boiler design

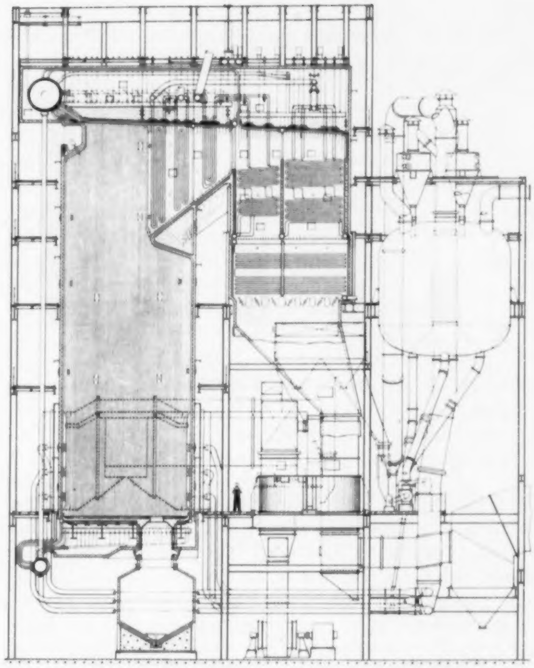

Fig. 4—Modified boiler design shows addition of water screen at the arch level of the furnace

lines feeds one front and one rear corner burner at the same firing level, with flow-balancing orifices installed in the rear burner line of each pair to compensate for the shorter transport distance.

The first two units of this contract were cased in steel plate of standard design. The third unit was cased in aluminum of special design including buckstays and bracing, the object being a full-scale comparison of the long-term costs of aluminum casing for outdoor boilers versus steel of lower first cost, which requires periodic painting and maintenance.

All insulated external ducting and piping to the boilers is lagged with aluminum.

Initial Operation

Initial operation of the first unit on crushed dried lignite fuel began in late December 1953. A number of operating difficulties were immediately encountered with the boiler-fuel transport system, furnace-slagging conditions, the fuel-separating cyclones and superheat and reheat steam-temperature controls. Through 1954 and 1955 design changes were made to alleviate these problems culminating with the fully successful operation of Unit No. 2 in December 1955. There have been no further modifications although Unit No. 3 and Unit No. 1 were modified during 1956 to the arrangement of Unit No. 2.

For the sake of brevity, Table II itemizes the specific problem areas and the solutions arrived at in the present design.

Final Modifications

The original design was considerably modified to deal with the problems mentioned. Beginning with the fuel handling system, the changes listed below were made:

Fuel Transport To Boiler Storage Silo. Because of erosion and plugging problems in the pneumatic transport lines from the process driers and erosion and fire problems in the receiving cyclones separating fuel and transport air, the pneumatic fuel-transport system between the fuel-process driers and the boiler fuel-storage silo was replaced by a closed mechanical conveyor of the suspended-flight type.

Burner-Fuel Transport. This eliminated 30,000 lb per hr of fuel-dust-laden transport air that formerly was exhausted into the burner-gas transport supply. The boiler-fuel silo could now be isolated from the burner-fuel transport system except for the solid-fuel flow through the feeders. Accordingly we could remove the 10 per

TABLE II—TABULAR LISTING OF INITIAL OPERATING DIFFICULTIES

Location	Problem	Modification
A	Excessive superheat and reheat steam temperatures	(1) Removal of portions of SH & RH (2) Installation of water tube screens at furnace outlet
B	Ash deposition of fibrous sintered ash in LTRH—plugging of gas passes	(3) Ash deposition minimized by reduction of gas temperature to 1550 F at this location. Installation channel cinder trap to protect airheaters
C	Freezing of slagspout Blockage of burners by shedding wallslag	(4) Lower furnace walls studded to retain slag coating (5) Fuel size reduced to 1% + 8 mesh
D	Plugging of fuel lines to burners	(6) Compound bends removed from fuel lines (7) Flow balancing orifices installed (8) Flow sensing devices installed
E	Erosion of refractory liners Fires in fuel separating cyclones	(9) Installation tubular aluminum target plates (10) Removed cyclones and replaced pneumatic with mechanical conveyor
F	Fuel carryover from storage into burner system	(11) Isolated fuel silo from burner transport system

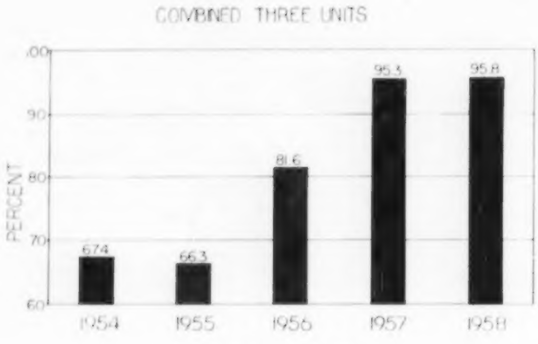

Fig. 5—Boiler availability

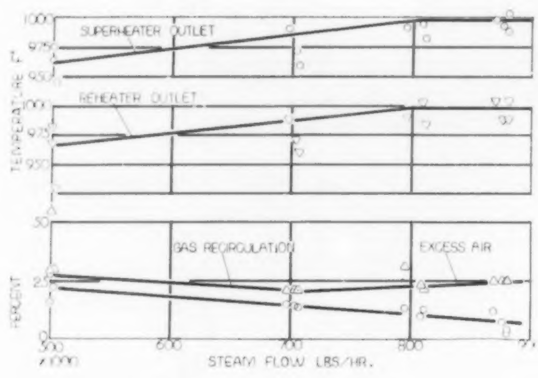

Fig. 6—Steam-temperature performance

cent oxygen limit that had been imposed on the burner-transport gas because of its contact with the stored fuel, and use primary air to convey the fuel from the feeder pickup point to the burners. (Note: An alternative duct arrangement was left in place to permit a blend of flue gas and air to be used when transporting hot lignite char from the feeders to the burners. The initial oxygen limit for this mixture was established by experiment at 14 per cent, of which 0.6 per cent is absorbed in the 1.1 sec residence time at a gas-char mixture temperature of 700 F.)

Additional transport capacity and static head was provided by the addition of a third primary fan taking suction from the hot-air duct after the metering airfoil, and supplying hot air to the transport gas-plenum chamber.

The boiler-fuel system was further modified by rearrangement of four fuel lines that had been the longest, most angular and the most susceptible to plugging.

By close fitting it was possible to eliminate 10 ft of horizontal run and 90 deg of angular deviation from each line, thus matching the length and angular deviation of those fuel lines that had experienced few pluggings.

The four shortest fuel lines were given an additional flow-balancing orifice in their transport-air supply lines. This had not been possible prior to isolation of the fuel silo from the burner-transport system because the cyclone exhausts contained fuel dust which could have deposited in the eddies around such an orifice, producing what was felt to be a potential fire hazard due to the tendency of the fine fuel dust to spontaneous combustion.

In addition, each fuel line upstream of the fuel-pickup tee was given a flow-sensing orifice with a differential relay to signal the operator should the airflow decrease in any line due to heavy fuel mixtures or to accumulation of oversize fuel particles. The feeder speed could then be reduced momentarily to allow the line to blow clear, and then restored to normal.

Furnace Modifications. To promote fluid slagging and flame stability at lower loads, studs were installed on the furnace wall tubes from the floor to an elevation above the upper burners, with the object of retaining the burner band wall slag on load reductions. Since this zone is always wet with running slag at higher loads, there is no effect on high load furnace heat absorption. At reduced loads the slag retention acts in the direction of assisting in steam-temperature control.

Five rows of furnace water screen tubes were installed at the furnace outlet to reduce furnace exit-gas temperatures by 250 to 300 deg F. These five rows originate through the furnace front wall below the arch-nose elevation, and are joined by three rows of alternately spaced tubes originating through the rear wall under the arch, to form two wide-spaced tube rows and three close-spaced tube rows directly ahead of the former furnace-outlet screen tubes. Water supply is by headers connecting to the center of five downtakes from the drum. This arrangement is shown in Fig. 4, a sectional side elevation of the modified unit.

Channel Trap. At the economizer gas outlet, a channel trap was installed to prevent large chunks of ash deposit falling onto the air preheaters. These channels are nearly vertical, Fig. 4, the lower ends passing into an enlarged cinder hopper. The hopper bottom was provided with a vertical 6-in. pipe bypassing the air preheaters and emptying the refuse into the ash hopper below the air preheaters. This hopper is serviced by the plant ash-disposal system.

Improvement of Unit Draft Losses. During the experimental period previously described, induced-draft-fan requirements had been excessive due to the plugging of the low-temperature reheater, superheater, and economizer, and the air preheaters. It has been apparent even before this time that the dust-collector draft loss was more than 1.5 in. wg greater than the design specifications. While the other components of the boiler could be cleaned to restore normal draft losses, it was imperative to have the dust-collector loss reduced to design loss to provide additional operating margin should partial plugging again occur, or should it not be possible to regain complete cleanliness of the air preheaters. This was accomplished by the manufacturer installing straightening vanes in the exhaust tubes of the separator, which reduced the dust-collector draft loss by 1.0 in. wg at design gas weight.

Additional draft-loss margin was provided by the furnace-water-screen installation. Because the screens had a greater effect on reheater heat absorption than on the superheater, the proportioning dampers under the economizer now shifted to another mean operating position which more nearly matched gas-mass flows through the two gas passes. This reduced the dampering draft loss at maximum load by about 2.5 in. wg.

Operating Experience With the Final Design Ash Deposits and Load-Carrying Ability

These three units have been operating for 3 to $3^1/_2$ years since their final modification. Full-throttle, peak-load operation has been carried for periods of more than one year without outages for manual cleaning. Manual cleaning at annual outages has been light. There are no indications of deposits in the lower-temperature reheater, low-temperature superheater or economizer of the type that once shut a unit down in 18 hr at peak load.

This improvement is demonstrated in Fig. 5 which shows unit availability from 1954 through 1958. The low availability shown for 1954–55 was due to extensive outages for rebuilding these units. During 1957 and 1958 boiler availability has exceeded 95 per cent.

Burner-Fuel-Line Plugging. The re-routing of fuel lines, installation of flow-balancing orifices in the primary-gas supply, the installation of flow-sensing orifices in the transport lines upstream of the fuel pickup tees and the control of fuel sizing has resulted in a major improvement in burner-fuel operation. Since the modification and interlocking of the fuel-line, flow-sensing relays with the fuel-feeder controls, burner-fuel line plugging is a rarity comparable to the occurrence of the same event in a pulverized-coal system. The number of occasions that the flow-sensing orifice relays have operated a feeder interlock has been few; however, it is felt that in these instances the relays have prevented line plugging by momentarily reducing fuel flow in adequate time to purge the line.

Steam Temperatures (Fig. 6). At full load of 800,000 lb per hr steam flow or higher, the full 1005 F superheat and reheat steam temperatures are obtained. Even at continuous full load, however, there are occasional daily variations in the furnace-wall slag insulation that affect superheat and reheat steam temperature by 30 deg F or more, a part of which is counteracted by the gas-recirculation control range.

As the steam flow is reduced, the convective effect of the furnace water screens on furnace exit-gas temperatures increases, and superheat and reheat steam temperatures fall off. At 500,000 lb per hr steam flow, steam temperatures of 950/950 F are obtained on reduction from full load. Continued operation at this load results in gradual loss of wall slag and steam temperatures are reduced to the range of 930/900 F superheat/reheat. We should note here that Unit No. 1 has a generally higher reheat steam temperature versus load characteristic than the other two units due to a 20 deg F higher reheater inlet steam temperature. The figures quoted above apply to Unit No. 2.

Bottom Slagging. Since the studding of the lower furnace walls, slagging begins on a cold startup at about 300,000 lb pr hr steam flow ($^1/_3$ load) and the units can be operated continously at loads above this level. At loads of 600,000 lb per hr steam flow and higher, the slag bed is flat and highly fluid. Some manual attention is required to insure against slag-tap plugging.

Floor-Tube Failures. Continuous operation of Unit No. 2 at full load disclosed another problem in the occasional failure of a floor tube by local overheating. The overheating, as shown in Fig. 9, involved a segment of tube metal as small as a 2-in.-diam circle and as large as a 2-in. by 6-in. oval, with the failed tube generally showing an attachment of extraneous metal on the tube surface around the rupture site.

Inspection of the floor conditions revealed several potholes in the new refractory filled with solidified iron and/or heavy metallic materials. The potholes varied in depth, some having the shape of an inverted cone with the apex nearly in contact with the floor blocks, others appearing as inverted parabolic shapes of shallow depth. After several failures we observed some pools of frozen iron that had penetrated the refractory and were in contact with the floor-block surface with some melting or fusion of the iron pool and the floor block in an area of several square inches. In each instance of failure, the floor blocks were melted away in a rough circle from 2 to 12 in. diam, and the edges of the crater blown in the refractory and slag by the escaping steam were partially iron, indicating the presence prior to the failure of a puddle of molten iron over the rupture site. Each failed tube had remnants of iron welded to it in the immediate vicinity of the rupture and metallurgical studies showed that overheating had occurred only within less than an inch of the point of attachment of the extraneous iron.

Experience with the first unit during early operation had demonstrated that iron and iron-bearing materials would gradually replace most of the floor refractory over a period of about a year. In this time, the floor would consist of a 2 to 4-in. layer of fibrous iron separated from the floor blocks by perhaps $^1/_2$ to 1 in. of refractory ma-

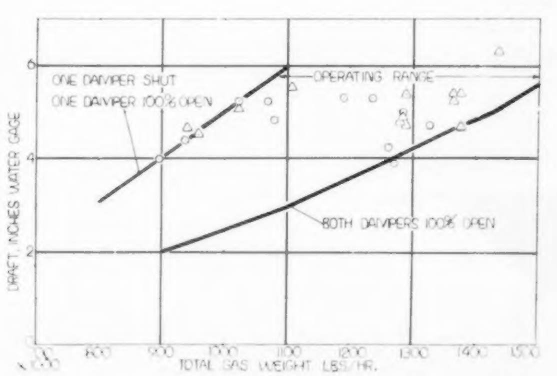

Fig. 7—Economizer-outlet draft

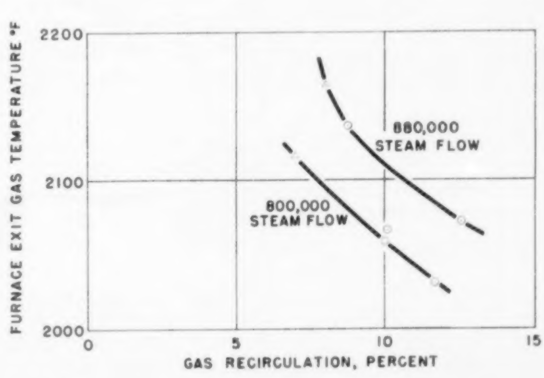

Fig. 8—Furnace-outlet gas temperature versus gas recirculation

Fig. 9—Floor failure developed from occasional tube failure from over heating

terial. The replacement appeared fairly uniform throughout the furnace. No failures of floor tubes had occurred in this unit other than one resulting from the expansion of the bottom allowing slag to run through into the casing, this being the result in turn of an erection error in not welding certain straps that normally restrain the outward movement of the side walls relative to the furnace bottom.

Fig. 10 shows a possible sequence of failure based on inspection of various floor sections without failures as well as the evidence of the failures themselves.

Starting with a new refractory floor and the generation of the usual iron compounds, either localized heating of part of the slag surface or localized spalling of the refractory due to variations in refractory quality or installation technique could result in iron puddles forming in depressions in the refractory as observed in these floors. Owing to the relatively high thermal conductivity of the iron-bearing materials the thinner refractory under such a puddle would be exposed to greater spalling tendencies than refractory of normal thickness under a flat iron-slag layer. Thus the puddle would tend to deepen itself by abnormal spalling and/or reaction with the iron.

In either case, the formation of an iron puddle that deepens faster than the normal penetration will result in a contact of molten iron with the cast-iron floor-block surface. At the moment of such contact, a large mass of molten iron at high temperature and high thermal conductivity is in contact with the block and tube through a small cross-sectional area, with a resulting instantaneous local heat flow that raises the tube-metal temperature in the area of contact to the level of failure at the operating stress. Upon rupture, the jet of saturated water and steam at 1550 psig blasts the molten iron, refractory and slag away from the floor, leaving a crater possibly 12 to 24 in. diam with a rim of frozen slag higher than the remaining floor level. The only evidence of the former molten-iron puddle is the thicker-than-average edge of iron around the slag crater and the remnant of iron welded to the tube around the rupture.

There were six floor-tube failures in 17 months prior to the regulation of fuel sizing. In the next 8 months there were 3 floor-tube failures as described and one slag breakthrough which did not rupture a tube. The operating company has since replaced the gunited and/or cast-chrome refractory floors with a magnesite refractory and increased the refractory depth from 5 to 8 in. In the past 2 years there has been only one floor-tube failure.

Present practice is to replace the magnesite refractory at 13-month intervals, although one floor has been in service longer than this without a floor failure.

Fuel-Size Control. The floor-tube failures cited in 1956 on Unit No. 2 were due in part to variations in local heating of the floor-slag surface by release of large heat quantities by combustion of large fuel particles on and in the slag surface. These variations could be the cause of uneven iron penetration, puddling and consequent failure. During the startup of Unit No. 2 as modified, in December 1955, fuel-size control had permitted the firing of fuel ranging up to 19 per cent plus 8 mesh, with considerable piling of large-size fuel on the floor, particularly against the walls. Since March 1956, fuel size has been controlled at not larger than 1.0 per cent plus 8 mesh, with resultant elimination of visual fuel drifting on the slag.

Performance of Channel Trap. The channel trap installed below the economizer to protect the air preheaters against gravel-sized particles of ash deposit has given no difficulty. A mesh screen of $^1/_{16}$-in. stainless-steel rods on $^1/_4$-in. centers, laterally and vertically was installed downstream of the channel sections to catch any material that passed the channels. The expectation was that it would be more desirable to plug the screen than to plug the air preheaters should the channels prove inadequate. To date no ash deposit has been found on the screens, indicating satisfactory performance by the channels. It should be noted, however, that the practical elimination of ash deposition in the primary reheater has made channel-trap performance somewhat academic.

The draft-loss performance of both channel trap and the back-up screen are reasonably small, the loss being about 0.4 in wg for the channels and 0.2 in. wg for the screen at a gas flow of 2500 lb/sq ft hr approaching at 670 F.

Aluminum Boiler Casing. The all-aluminum casing applied to Unit No. 3 has given no problem to date. On one occasion in early operation, blocking of a burner

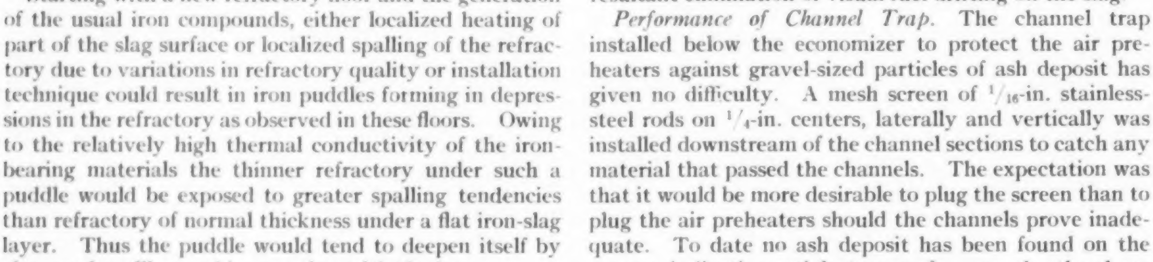

Figure 10—Sequence of floor-tube failure-left, the original floor construction; middle, the molten iron penetration, right, the actual tube failure

Fig. 11(a)—Reheater ash deposit in place

Fig. 11(b)—Reheater ash deposit removed

secondary-air port caused hot air to be diverted from the windbox under the casing, resulting in the deformation of a short vertical aluminum-channel section used as a casing stiffener. The damaged section was removed and a replacement welded in by inert-gas-welding techniques. There have been no recurrences.

Burner and boiler design in recent years has moved toward the support of burners directly from the furnace walls with elimination of slip joints at the juncture of windbox and casing, and the substitution of seal-welded joints. With present types of construction the incident referred to could not have occurred.

Some Special Notes

Furnace Performance

These units are successfully burning dried lignite of a size consist 1 per cent plus 8 mesh and about 18 per cent minus 200 mesh in a tangentially-fired, slag-tap furnace of normal design. Fig. 1 compares the size consist of these fuels with standard stoker sizing and with pulverized lignite sizing on a USB Mines coal size chart.

A studded tangentially-fired, slag-tap furnace similar to these units could be designed to burn this fuel successfully in a size consist as coarse as 5 to 7 per cent plus 8 mesh and 12 to 14 per cent minus 200 mesh. This performance was not intended for the subject units, and cannot be attained by them as built because their specific floor design will not withstand high heat-release rates in the floor slag. While no exact limit can be specified, the operating fuel size limit has been established by visual observation of the amount of fuel impinging on the floor slag surface to not in excess of 1 per cent plus 8 mesh. At this size range, the floor-slag surface is clear and few fuel particles visibly burn in the slag.

The furnace-wall insulation effect of this fuel ash is greater than expected of pulverized slag-tap fired Eastern coals, or of pulverized Midwestern coals fired in dry-hopper units. Whether this effect is due to the size consist of the fuel or to the chemical nature of the ash, we are not prepared to state.

Distribution of Ash Fired

Ash distribution and carbon loss were determined on Unit No. 2 as finally modified with furnace screens and furnace-wall studs. A thorough dust-sampling traverse was made at the economizer interbank plenum using three inserts from each side of the unit and traversing three points at each insert. A series of 7 tests was run at 25 to 35 per cent excess air with 3 to 14 per cent gas recirculation, primary-air transport, fuel size up to 2 per cent plus 8 mesh, and full-load steam flow of 810,000 to 860,000 lb per hr. These data are shown in Table III.

Dust loadings indicate from 22 to 30 per cent of the ash fired appears as fly ash, the remaining 70 to 78 per cent of the ash being removed as slag. It is likely that the fraction of ash fired to the slag would have been somewhat greater when firing coarser fuel.

Carbon heat loss to fly ash ranged from 0.3 to 0.5 per cent of the heat in fuel fired. No combustible has been found in the slag.

Ash-Deposition Characteristics

The ash deposit which was most troublesome in these units was a fibrous sintered growth, Fig. 11, that occurred in the primary reheater at gas temperatures of 1700 to 1800 F. Microscopic examination of many pieces of this type deposit showed that the particles were perfectly spherical as is true of normal pulverized-coal fly ash due to freezing of the molten droplet in gaseous suspension as it passes the furnace outlet. Also, these spherical particles were attached in tangent contact with no perceptible deformation of the spheres, indicating that impingement and attachment occurred when the ash particle was cooler than its temperature of initial deformation. Attachment was not due to plastic deformation of the fly-ash particles, but to some bonding agent present at the surface of the particles.

Fig. 12 is a photomicrograph of fly ash from the dust collector showing the perfect spherical particle shape of normal particles. Fig. 13 is typical of many photomicrographs of LT reheater deposits showing tangent

TABLE III—FLY ASH DUST LOADING AND CARBON LOSS

Test No.	244-C	245-C	246-C	247-C	249-C	250-C	251-C
Date	3/8	3/9	3/19	3/22	...	...	...
Steam flow, 10^3 lb/hr	840	840	860	850	810	810	859
Excess air	33	35	40	37	26	26	25
Gas recirculation, %	7.0	6.7	3.6	3.5	11.3	13.0	10.1
Dust loading, lb dust/10^3 lb gas	3.42	3.48	3.97	2.82	3.06	3.29	3.11
Combustible, %	8.4	6.3	4.4	10.6	7.5	5.45	7.1
Carbon heat loss, %	0.47	0.37	0.29	0.49	0.38	0.30	0.36
Ash fired, lb/10^6 Btu	14.7	14.5	14.6	14.6	14.6	14.6	14.6
Ash in fly ash, lb/10^6 Btu	3.62	3.83	4.47	2.92	3.26	3.63	3.27
Ash to fly ash, % ash fired	24.6	26.4	30.6	20.0	22.3	24.9	22.4
Fuel size, % + 8 mesh	0.6	0.6	0.5	0.7	0.4	0.6	0.5

attachment between fly-ash spheres with no deformation of the particles.

Many chemical analyses were made of these deposits, but the exact nature of the bond was not determined, perhaps due to the minute amount of such agent that would be necessary to sinter these deposits. The underlying deposit next to the tubes of the primary reheater was enamel-like and contained a high proportion of calcium sulfate, a compound that exists in the raw lignite in amounts varying up to 50 per cent. The outermost portions of the thick deposit resembled normal lignite ash in chemical composition. For some time it was suspected that the bonding might be a fusible coating of condensed alkali compounds on the outside of the fly ash cenospheres, as described by Crossley (2) and Marskell (3), despite the low concentration of alkali found in the deposit. In March 1955 we received a preprint of a paper by Crumley, et al. (4), describing calcium-sulfate-bonded deposits observed in England which strikingly paralleled our primary reheater-deposit analysis. Chemical bonding could occur at gas temperatures much below the ash-softening or initial deformation temperatures of the fly ash. The temperature below which bonding would not occur is dependent on the nature of the bonding material, being about 1500 F for simple alkali compounds.

These bonding actions have been attributed to volatilization of chemical compounds from the fired ash in the flame or slag. Volatilization depends upon high flame temperatures (above 2700 F) which are obtained in most slagging-type furnaces. In dry-bottom furnaces, developed flame temperatures are lower and volatilization is less likely. In addition, slagging-type units firing coarse fuel tend to concentrate the volatile-ash compounds by removing 70 to 90 per cent of the ash fired as slag, so that all the volatile material appears in the fly ash with a small part of the original nonvolatile ash. A dry-bottom unit passes 60 to 80 per cent of the ash fired out of the furnace as fly ash, thus diluting the effect of any volatilization with the bulk of the nonvolatile ash.

Today, these units are operating continuously with gas temperatures entering the primary reheater of 1530 to 1560 F. Ash deposition at this point is light enough that a retractable sootblower operating on a 12 to 24 hr cycle can maintain the section in clean condition for up to 13 months of full-load operation with little manual cleaning of the reheater required during the annual outage.

The ash deposition that formerly occurred in the primary reheater now occurs in the high-temperature reheated pendant zone, where it can be removed by retractable sootblowers and dropped into the furnace over the arch slope. While some of this material is blown back into the primary reheater, the amount is small enough to be broken up by the retractable sootblower at this point, and the growth of deposit at this location is so slow that no appreciable build-up of fly ash occurs on the blown-back chunks.

In summary, we can state that the permissible gas-temperature level at any particular location in a solid-fuel-fired unit is not a function of ash-softening-temperature range, but depends on the nature of chemical bonding agents present in the coal ash. Also, the more important criterion of gas-temperature level is the capability of the heat-absorbing surface at that point to receive, remove and dispose of ash deposits formed in place. The fundamental limitation encountered in these units was not alone the fact that deposits were formed at a given temperature level, but that the horizontal primary-reheater surface was not capable of handling such

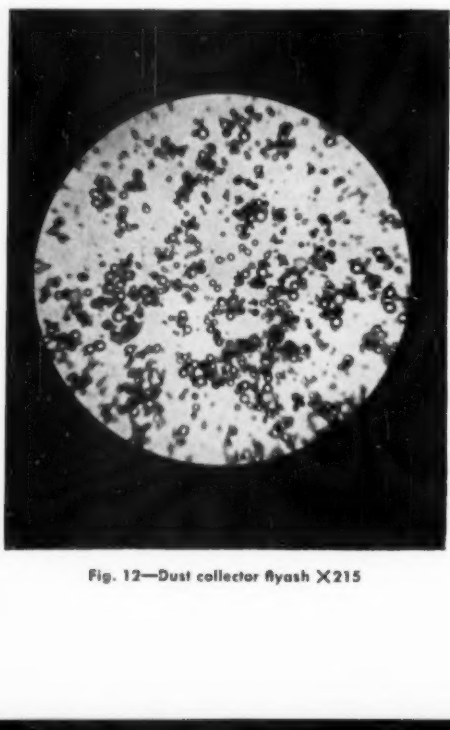

Fig. 12—Dust collector flyash ×215

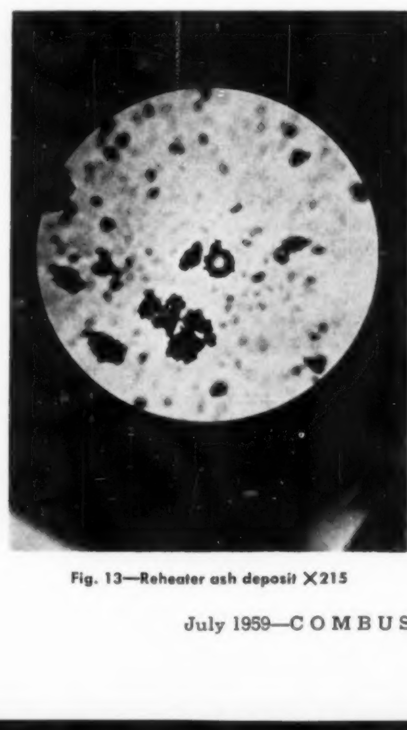

Fig. 13—Reheater ash deposit ×215

TABLE IV—CHEMICAL COMPOSITION OF LIGNITE ASH

	Ash in Fuel as Fired				Ash Deposits Removed From Boiler				
		Range of 34 Fuel Samples						H.T.	H.T.
	Specification	Min.	Max.	Mean	Primary Reheater Deposits			Reheater	Superheater
SiO_2	32.5%	8.4	28.9	21.1	9.1	14.9	23.4	19.3	10.7
Fe_2O_3	5.3	9.0	13.9	10.8	9.8	7.3	6.0	7.3	36.2
Al_2O_3	19.3	9.3	25.1	12.9	12.6	0.	13.8	5.8	6.6
P_2O_5	0.08	...	...	...	0.	0.	0.24	...	...
CaO	22.2	19.8	30.3	22.7	27.5	25.1	21.1	18.6	15.7
MgO	3.2	3.0	12.6	6.2	3.9	4.8	3.0	4.8	0.8
$(Na, K)_2O$	1.4	0.7	9.5	3.6	...	...	0.97	...	...
SO_3	14.3	17.9	24.1	21.0	35.6	47.1	26.5	42.7	28.0
TiO_2	1.6	...	...	...	...	...	1.6	...	...

ash deposits. This function can be performed by pendant-type surface of wider spacing, and in more recent design, by platen-type surface which can be operated with impunity at gas temperatures above the softening temperature of the ash when placed directly over the furnace cavity.

Chemical Composition of the Lignite Ash

Table IV gives the range of chemical analyses of ash in feeder samples of dried lignite taken daily over a period of many weeks. Note particularly the high percentage of calcium and sulfate in nearly stoichiometric ratio.

During this period, the units were inspected twice daily or more often and written notes and sketches prepared to show the extent of furnace-wall slagging, bottom slag conditions and unit heat-absorption distribution. We could make no correlation with the variation in daily ash chemical analyses.

Fuel Abrasion

These fuels exhibit a remarkable abrasion when transported in suspension. The original pneumatic transport between the driers and the boiler-fuel storage silo had erosion problems in the fuel-line bends within a few months of start-up. Boxes were constructed at the elbows to allow the fuel to abrade on a layer of retained fuel, but these too eventually wore through. This system has been removed and replaced by a mechanical conveyor system.

The boiler-burner, fuel-transport system has also had its share of erosion problems. Because of the fuel-size consist, transport velocities found necessary to assure flow were somewhat higher than the best design practice in pulverized-fuel lines, being 90 to 100 fps maximum rather than 70 to 80 fps used for fine coal transport. There is some evidence that larger size coal particles are more abrasive than fine coal. As a result, the burner-transport lines have suffered considerable erosion in service. The original cast-iron fittings wore through in about 10 months in fuel lines operating at 120 fps velocity and in not more than 14 months in lines operating at 80 fps velocity.

At present the operating company is using Ni-Hard cast fittings with 1-in. walls. Both Ni-Hard castings and burner parts have a life of about 2 years before being built up with hard-surfacing rod, after which an additional year of service is obtained. This corresponds to a life expectancy of 130,000 tons of fuel per burner.

Firing of Lignite Char

Char has been fired only intermittently for periods of less than 2 weeks each, the limitation being in the deposition of the tar production. Tar storage is limited and carbonizing runs must end when tar capacity is filled except when an order is being made up for immediate shipment.

The carbonizer will supply char to carry approximately $^1/_3$ of full load on one unit. To date char has not been fired alone, since electrical demands have required full-load boiler operation. Observation of mixed lignite and char firing with primary flue-gas transport to the burners has disclosed no perceptible difference in the operation of the furnace. Slagging in the bottom appears normal, and furnace-wall deposits appear to be the same as when firing dried lignite alone.

When hot char at 900 F is handled in the fuel silo with dried lignite at 200 F, there is a tendency to carbonize the dried lignite in contact with the char, driving off light oil and tar vapors. These have caused no particular operating problem as yet, but the vapor seeps through fuel downspout and feeder gasketed joints, immediately condensing in the ambient air. The resultant wetting of external surfaces with tar and oily liquids is a minor nuisance.

While the char has slightly less volatile matter (25.5 per cent versus 39.5 per cent) than the lignite, it is finer in size, containing significantly more minus 200-mesh material, and it is a very reactive fuel.

Effect of Flue Gas as a Primary Fuel-Transport Medium

Dried lignite has been fired using 100 per cent hot-air transport from the feeders to the burners. When firing lignite char, this air is diluted by flue gas to 14 per cent oxygen because of the reactivity of the hot char. Originally burner transport was designed for a mixture of flue gas and process transport air at 12 per cent oxygen.

Since there has been some question as to whether the use of primary gas transport had contributed to the firing conditions, a trial operation was conducted for 2 weeks using dried lignite and flue-gas-air at 14 per cent oxygen for fuel transport in a unit that had received the final modification. The result indicated that full-load operation was not significantly altered by the primary flue gas.

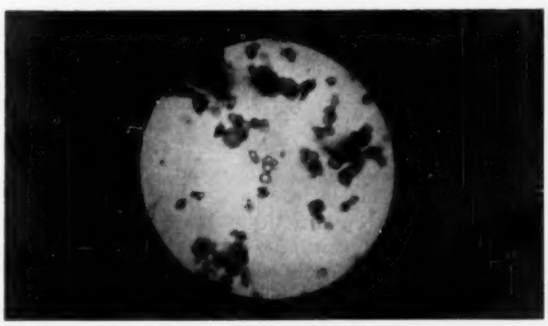

Fig. 14—Reheater ash deposit ×215

There is an effect on bottom slagging ability at reduced loads which raised the lowest slagging load from 300,000 lb per hr to perhaps 350,000 lb per hr steam flow. Furnace-wall slag and ash deposition in the primary surfaces are not perceptibly changed from the 100 per cent primary-air operation. Steam-temperature control is improved since the total gas-recirculation capability is increased when using the primary transport fans on gas.

Fig. 8 shows the effect of primary gas and recirculated gas on furnace gas-exit temperatures. In this unit, the flue gas recirculated into the furnace acts to reduce furnace exit-gas temperatures, whether introduced through the burners or above the windbox.

Conclusions

The fuel used in these units is unusual in many respects, since dried lignite alone cannot be justified as a power-plant fuel, except as a standby fuel when the chief fuel is lignite char processed from the dried lignite. Normal practice would provide raw pulverized-lignite-firing in dry-hopper furnaces, so that separate stack losses would not be incurred by separate drying and combustion facilities, and less manpower would be required to operate auxiliary equipment.

These units demonstrate that an unusual fuel of unusual size consist with an ash of unusual chemical bonding tendencies can be burned successfully in a slagging boiler furnace of near-normal design. The essential design feature must be the determination of any special chemical-bonding tendencies of the ash, and the arrangement of unit heat absorption to provide surfaces of proper ash-deposit-handling characteristics at all locations where flue-gas temperatures exceed the lower temperature limit for chemical bonding.

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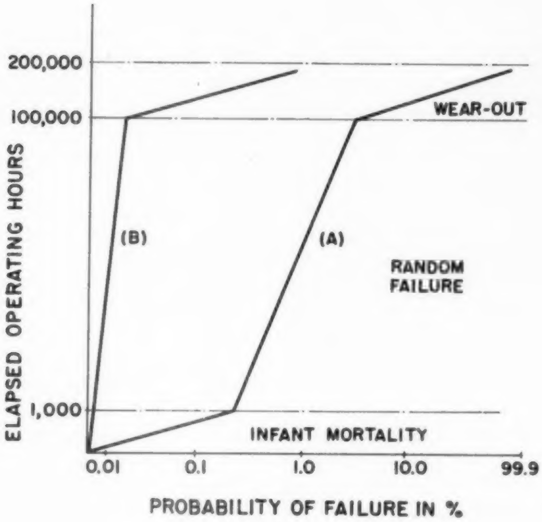
Symposium on the Optical Pyrometer Temperature Scale

To facilitate the exchange of information and ideas on high-temperature pyrometry, a Symposium on the Optical Pyrometer Temperature Scale was held at the National Bureau of Standards, Oct. 23 to 25, 1958. Sponsored by the Heat Division of the Bureau and the High Temperature Group of Argonne National Laboratory, this Symposium concentrated on present temperature scales and calibration practices, recent improvements in optical pyrometer techniques and instruments, and the possible use of the temperature scale beyond 4000 K. Chairman of the Symposium was C. M. Herzfeld, Chief of the Bureau's Heat Division.

In the last few years, the interest in high-temperature measurements has created a demand for optical pyrometers capable of greater precision and accuracy. This need has raised many questions about procedures for realizing the International Temperature Scale at high temperatures (above 1063 C) and about the calibration, use, and manufacture of optical pyrometers. Recent studies, principally at the National Bureau of Standards and Argonne National Laboratory, have shed new light on some of these problems. To communicate these ideas as rapidly and conveniently as possible, and at the same time provide an opportunity for discussing individual problems, the Symposium on the Optical Pyrometer Temperature Scale was planned.

Trends in the Bureau's work on optical pyrometry were outlined at the beginning of the conference by Dr. Herzfeld. He pointed out the necessity of improving methods of temperature measurement in the range 800 to 4000 C under ideal conditions. Here accuracy, precision, and convenience of operation need further improvement. An extension of methods for measuring temperatures under ideal or approximately ideal conditions in the range 4000 to 10,000 C is also required. In addition, improvements in temperature measurement under nonideal conditions, such as in flames and complicated systems, are needed along with more fundamental research leading to new and better ways of measuring temperature.

The procedure employed at Argonne to establish the temperature scale in the range of 1000 to 2500 C was discussed by R. J. Thorn and G. H. Winslow of that laboratory. The starting point for the calibration was the freezing point of copper, which has been determined as 1083 C on the 1948 International Temperature Scale. Above the freezing point of copper a black body constructed of tungsten, contained in a vacum and heated inductively, was employed as a light source. Some advantages of using a black body rather than a tungsten strip lamp were discussed. Effective wave lengths, calculated from the measured transmissions of the pyrometer red filter and the standard visibility function, were presented. The National Bureau of Standards and Argonne National Laboratory optical pyrometer temperature scales agree within 1 C at the gold point, but differ by 4 deg above 1600 C. It is suggested that the most likely source of the difference lies in the effective wave lengths.



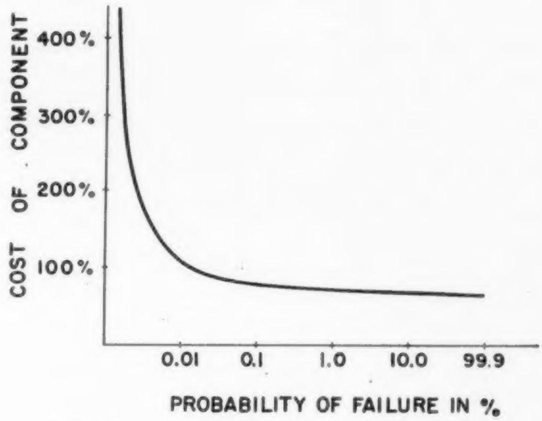


Fig. 2—Relationship between cost and probability of failure

Fig. 1—Failure curves can be developed, once frequency of failures has been established

Criteria of Equipment Reliability Evaluation*

Availability or equipment reliability are matters of vital concern in power plant operation and, of course, in equipment purchase. Here a leading figure in the design and application of the boiler feed pump probes into the thinking behind attempts to evaluate reliability and poses the question as to whether it will ever be possible to confine evaluations to statistical studies.

By IGOR J. KARASSIK†

Worthington Corp.

IT is characteristic of the components of modern technological processes that they are required to operate under more severe and more exacting conditions than ever before. It is just as characteristic that these components are required to perform with a greater degree of reliability, because unscheduled interruptions, particularly those affecting production, have become more important. In other words, just when equipment failures are becoming more costly and less welcome, they have also become much more likely to occur as a result of the increasing complexity of our technological processes and of all their component parts. We are faced with a conflict between the need of greater reliability and the impact of new problems which threaten this reliability.

My studies of the reliability of one specific component of the steam power plant, the boiler feed pump, have led me to the realization that the very concept of "reliability" requires clarification. Reliability is a concept, an idea, but it is also a real thing even though it cannot always be expressed numerically. Once this is understood, it becomes possible to apply logical steps in the evaluation of different designs, techniques, applications and operating practices. It is therefore with a clarification of the concept of reliability and with a discussion of the practical meaning of this concept that the present paper will deal.

Because of my long-term association with boiler feed pumps, I have chosen to use this particular piece of equipment to illustrate this search for new criteria of reliability evaluation. I fully realize that I risk finding myself between two camps. On one hand, there are the reliability experts to whom the tremendous impetus of aircraft and missile construction have given great insight into this problem. To them this paper may appear as merely an elementary introduction to the subject. And on the other hand, there will be found engineers to whom a search for a new approach into equipment evaluation will appear as an entirely unnecessary academic exercise. I can merely hope that I find some congenial company between these two camps to whom this analysis may be of use and of interest.

* Presented at the Semi-Annual Meeting of the ASME, St. Louis, Mo. June 14-18, 1959 as paper No. 59-SA-2 under the title "A New Search for Criteria of Equipment Reliability Evaluation."

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What Is Reliability?

This word, "reliability," is possessed of very intangible characteristics. I have frequently tried to define it, but never have I succeeded in improving a definition I once read in the advertisement of a firm manufacturing components for electronic computers: "The reliability of a particular component or system of components is the probability that it will do what it is supposed to do under operating conditions for a specified operating time."

This definition illustrates how difficult it must be to assign a significant number to the reliability of a boiler feed pump. To calculate or predict a probability, it is necessary to carry out statistical research with a number of units much higher than is available for such research. To define *operating conditions*, it is not sufficient to list required capacities and pressures, prevailing temperatures and expected variations of these three items. It is also necessary to predict any and all possible other factors and *events* which may interfere with the ability of the pump to "do what it is supposed to do."

Probabilities: Definitions and Relationships

We said that reliability is the probability that a certain component or system of components will do what it is intended to do. But what is probability? If we consult a dictionary, we find that of the precise meaning of "probability," there are conflicting views among philosophers, mathematicians, and statisticians. But for our particular purpose we can do with a reasonably simple definition, equating the term "probability" to that of "chance." In other words, if chances are one out of a hundred that a certain event will occur, the probability is one out of a hundred, or 0.01. The *Total Probability* of all alternate events is 1.00, that is 100 per cent. And the reliability of a component is the probability that it will not fail, or 1.00 less the probability of failure; if ten components out of a thousand similar components fail, the probability of failure is 0.01 and the probability of successful operation or reliability is 1.00 less 0.01, or 0.99.

We know something more about probabilities. We know that the probability of a series of events is the product of their individual probabilities. If we deal with a system of one hundred components which, when operated together, make up a steam power plant and if the successful operation of the power plant requires the successful operation of each component, then the reliability of the power plant is the product of the reliabilities of each one of the components. And if the individual reliabilities of the components are assumed to be 0.99, the reliability of the power plant will be 0.99 multiplied by itself one hundred times, or 0.3665. In simple terms we could expect a plant to be out of service about two thirds of the time and only one out of each three steam power plants to operate satisfactorily. Two plants would be in unscheduled outage.

This is certainly a cheerless conclusion to reach and one that we know to be contrary to experience. After all, unscheduled outages in steam power plants are the exception rather than the rule. Then, what is wrong with the assumption which we have made? There are certainly at least one hundred components in a steam power plant, the successful operation of each one of which is essential to the operation of the plant. The difference between our calculations and operating experience arises, more than likely, from assuming that the reliability of each component was only 0.99. Had we assumed an individual reliability of 0.999, the overall reliability would have quickly climbed from 0.3665 to 0.906.

Let's try again. If the individual reliability is raised to 0.9999—one failure out of ten thousand units—the overall reliability becomes 0.991. Now only one steam power plant out of one hundred will be experiencing an unscheduled outage. Of course, the reliability factors for a group of dissimilar components do not fall neatly into line as 0.99 or 0.9999 but are probably a family of factors ranging between 0.99 and 0.9999. Still, this example is useful to illustrate the cumulative effect of the reliability of a large number of individual components.

Of course, some distinction can be made as to the extent of equipment failure. There is a marked difference between a complete pump failure in a plant with no standby pump and a leak in a heater tube where the heater can be temporarily bypassed for repairs without shutting down the steam plant. Likewise, there may be some argument as to the number of items comprising the whole. Is each heater considered a component or each tube in the heater? Is the pump with its drive and controls one unit, or three? Or is each pump made up of hundreds of individual components, each with its own reliability factor, each factor of equal weight in evaluating overall pump reliability? Admittedly, this choice of numbers will influence the meaning of the reliability factor. But in our particular case, the question is strictly academic; we are not aiming at establishing a valid, quantitative value for the probability of failure of a steam plant, but rather at developing a climate—a mode of thinking of reliability and of all the factors that may affect it. Regardless of how much we may learn about precise numbers, the consideration of conditions that could affect reliability could in itself be our most important achievement.

The moral of all this—for there is a moral to these calculations—is that minute variations in the individual reliabilities of the components that comprise a steam power plant will have a telling effect on the satisfactory operation of the entire plant. When we make an effort to improve the reliability of a given piece of equipment even the slightest bit, we aim to achieve very important improvements in the sustained operation of the process or of the plant which will be served by this equipment and this remains true whether we can measure reliability or not.

Can We Classify Failures?

But even if we cannot assign a significant number to the reliability of a component of a steam power plant such as the boiler feed pump, we can attempt to classify the failures of which this equipment can be a victim. I recently read an article on maintenance problems[1] which gave me an entirely new point of view on the subject of reliability. It proposed a classification of service interruptions from component-part failures into three groups: (*a*) Infant mortality, (*b*) random failures, (*c*) wear-out.

[1] "Developments in the Analysis of Maintenance Problems," by J. D. Quinn, E. I. du Pont Company, *Mechanical Engineering*, October 1957, p. 931.

TABLE 1 CAUSES OF INFANT MORTALITY OF BOILER FEED PUMPS

a) FAULTY DESIGN	b) FAULTY COMPONENTS	c) FAULTY INSTALLATION	d) IMPROPER OPERATING PROCEDURE	e) UNFAVORABLE EXTERNAL CIRCUMSTANCES
1) Hydraulic inadequacy	1) Inclusions in forgings	1) Inadequate suction piping configuration	1) Inadequate cleaning of suction piping	1) Electrical disturbances
2) Mechanical inadequacy	2) Porous castings	2) Distorting piping stresses	2) Inadequate warm-up	2) Main unit sudden load reductions or complete trip-outs
3) Inadequate choice of materials	3) Errors in machining	3) Inaccurate alignment	3) Faulty operation of valving	3) Control failures
	4) Errors in assembly			

Infant mortality is defined as that group of failures which occurs in the early stages of operation and which can be ascribed to faulty components, faulty installation or initial operating procedures. Random failures indicate a situation that could be classified as "out of control." The wear-out classification can be a normal situation if the operating hours approach the expected or designed life of the components.

The number of operating hours for a large group of machines or components can be plotted against the probability of failures. Such a typical curve is shown in Fig. 1. The shape of the curve discloses a very definite subdivision of *all* failures into these three categories. But what is more important, it gives an immediate indication of the areas where improvements can be made by careful analysis and changes in design, operating procedures, and so on. For instance, if faulty installation is causing excessive infant mortality, proper training of the mechanics will remedy this problem. Excessive random failures may indicate the inadequacy of the components to withstand certain unanticipated overloads. Wear-out which occurs considerably below the expected life of the equipment may require product redesign to meet the prevailing operating conditions which apparently are too severe for the existing design parameters.

Such a curve can be constructed readily if we are dealing with a mass-produced and mass-applied item on which reasonably accurate records are available. Thus, a situation, initially described by curve A in Fig. 1, can be improved to yield curve B by reducing infant mortality and random failures.

But when it comes to boiler feed pumps, there is an immediate obstacle; namely, the number of high-pressure boiler-feed-pump installations is not high enough for such statistical studies to be valid, and accurate records of failures in the field—of either minor or major nature—are not readily available.

One may say, then, why introduce this concept of failure classification when we cannot prepare a quantitative curve which would give us any clue to the wisest course to follow in our choice between different designs or arrangements? I feel that the concept is useful for focusing our attention on the difference which exists between various types of boiler-feed-pump failures. We can begin by dispensing entirely with the wear-out problem on the assumption that the life of the modern high-pressure boiler feed pump is of the order of 100,000 hr, if no other causes of failure interfere with the gradual process of wear in the internal clearance parts. We can likewise pay just nominal attention to the random-failure portion of the curve on the assumption that the user selects his equipment with the thorough understanding that some designs can withstand certain transient operating conditions better than others.

Infant Mortality

We are left to deal with infant mortality. What are the factors, then, which contribute to the infant mortality of boiler feed pumps? If we were to prepare a check-list of the potential hazards, we would first classify them into the following sub-groups:

(*a*) Faulty design.
(*b*) Faulty components.
(*c*) Faulty installation.
(*d*) Improper operating procedures.
(*e*) Unfavorable external circumstances.

Each of these sub-groups can be broken up further into a number of individual causes, as shown in Table I.

Some authorities refuse to include faulty design or faulty components among the causes of infant mortality on the ground that these two categories of failures belong to a production phase preceding the "birth" of the equipment. But this is strictly a matter of semantics and, for our purposes, both causes should be included in our considerations if we are to make a thorough analysis of reliability factors; that is, they should be listed, but we need not enter into a detailed study of these causes here. We must assume on one hand that the manufacturer will seldom install a completely untried piece of equipment for regular commercial operation, and on the other hand that any selective analysis between several designs is made by an engineer capable of understanding and evaluating differences in design and material potential.

Similarly, faulty components should be, and generally are subject to elimination or at least major reduction through careful inspection.

The remaining three subgroups of infant-mortality causes are well worth most thorough attention. In my estimation, they are the most frequent causes of boiler-feed-pump difficulties. To begin with, there is no suitable excuse for any failures caused either by excessive

piping stresses which distort alignment in operation or by inaccurate field alignment. Such matters are readily subject to measurement and recheck.

Inadequate suction-piping configuration is something else again. Until quite recently, suction conditions were well enough understood with regards to steady-state conditions, but rather vaguely when it came to transient-load conditions. I should add that a close relationship exists between this particular source of trouble and one of the items in subgroup (*e*); that is, sudden load reductions or complete trip-outs of the main unit. Here, it is further education of plant designers in this particular phase of the subject that is an essential ingredient of failure reduction.

In the realm of improper operating procedures, we must single out inadequate cleaning of the suction piping and of the equipment connected to it as the prime offender. Probably the most serious hazard to a boiler feed pump during its early life is the presence of foreign matter such as mill scale, welding spatter or brittle oxide particles which can lodge in the close internal running clearances and cause major damage.

Inadequate warm-up procedures run a close second in the list of boiler-feed-pump difficulties that I have encountered.

When it comes to unfavorable external circumstances, it would seem that neither the boiler-feed-pump manufacturer nor the user would have any control in this area And yet, that is not true. Of course, it is not possible to so regulate electrical-distribution systems that no sudden changes in station load will take place, no electrical disturbances will occur. But once the designer and the user are made to understand the exact effect of these transient conditions on the boiler feed pump, they need no longer remain a major cause of infant mortality—or, for that matter, of random failure. The designer can build into his boiler feed pumps a greater degree of tolerance for the severity of operating conditions imposed by the transients. The power-plant engineer can incorporate into the overall design of the feedwater cycle such necessary precautions and protections which will minimize the effect of the transients on the boiler feed pumps.

Reliability and Economy of Operation

We have demonstrated the thought that one of the most important considerations in the selection of equipment to serve in a steam power plant is the reliability of this equipment and its ability to give a long life of uninterrupted service. But equipment has still another characteristic and that is economy of operation. And there has always existed a tendency to give efficiency, that is economy of operation, an equal or even greater weight than reliability. We must pause, therefore, and consider how justifiable are efficiency evaluations and what factors must be examined before we can look at these evaluations in a proper light.

Let us again take the boiler feed pump for our example. There is no doubt, of course, that a pump with a higher efficiency will consume less power and will have lower operating costs—at least on paper. But the fundamental fact we must keep in mind is that the question of efficiency is unalterably linked with that of reliability. In general, it can be stated that the desire for higher efficiencies and for maximum reliabilities are incompatible.

For instance, one of the great sources of power losses in a centrifugal pump is the disk-horsepower; that is, the power expended to drag the impellers through the liquid surrounding them. These losses increase with the fifth power of the impeller diameter. Therefore, power can be saved by reducing the individual impeller diameters and the head produced by each impeller and by increasing correspondingly the number of stages. But this solution increases the shaft span of the pump and the shaft deflection. Unless we increase internal clearances to compensate for this increase, we will have reduced the reliability of the pump.

Another source of efficiency improvement lies in the reduction of internal clearances. For example, a high-pressure boiler feed pump can gain in efficiency merely by reducing its internal clearances. I need not comment on the effect of such a reduction on pump reliability—save to say that this reduction, unfortunately, cannot be given a quantitative evaluation as easily as the gain in efficiency and the savings in power consumption.

As a matter of fact, evaluation of power costs in the case of a boiler feed pump is somewhat inconsistent with the method used in selecting pump-design conditions. These are generally determined by plotting the required system-head curve to a capacity anywhere from 6 to 20 per cent beyond the maximum demand and, in some cases, adding a further safety margin to the pressure. All this excess capacity and pressure are provided as a margin against possible boiler swings and against pump wear and this is considered to be an absolute requisite for full power-plant reliability. But it would seem that a philosophy based on adding an arbitrary margin to the capacity and pressure requirements, while insisting on evaluating minute differences in the power consumption of various pump selections, is not sound. It is as false an approach to reality as that of any engineering calculations which start with very approximate assumptions and use logarithms to yield an answer to five significant figures.

It is interesting to note that specifications which include efficiency evaluations frequently incorporate the statement that "everything else being equal," power savings will be evaluated at so-and-so-many dollars per horsepower. "Everything else being equal" is a phrase which has been much overworked and frequently misused in the engineering vocabulary. It is so seldom that everything else can be equal when one compares designs based on entirely different conceptions, that the expression could well be allowed to fall into oblivion.

First Costs Versus Reliability

And what of first costs? This question in itself could serve as a subject of a separate paper—of several papers, as a matter of fact. But we can at least indicate a point of departure for such a study. If we limit ourselves to a strictly qualitative approach, we can suggest that the shape of a curve showing the relationship between the cost of a piece of equipment and the probability of failure has the general characteristics of a hyperbola, as shown in Fig. 2. There will always be a point where very minor savings will result in a tremendous increase in the probability of failure. There will also be a point at which any further reduction in this probability can only be achieved at a cost increase which is hardly justifiable.

If such a curve could really be constructed, the choice of equipment would be a relatively simple matter.

Either one of the two approaches could be used. The maximum permissible probability of failure would be determined and, in turn, would determine the price that one would have to pay for the equipment in question. The alternative would be to determine the maximum price that one would be willing to pay and to learn living with the resulting probability of failure. Alas, such curves can only exist in our imaginations, at least for the present.

The next degree of refinement would consist of asking ourselves the question whether such a curve is continuous. Very probably not, since we can immediately seize on an example of discontinuity. Using the comparison of 5 per cent chrome-steel casings for axially split boiler feed pumps (used instead of straight carbon steel to avoid corrosion-erosion under the attack of pure feedwaters) we note that an increase in cost of some 20 to 25 per cent reduces the probability of failure from a fifty-fifty chance to something infinitesimal. In other cases, the curve may be more continuous in character; added costs of more thorough inspection improve reliability in a continuous relationship.

But whatever the exact nature of this relationship, the general shape of the curve in Fig. 2 can teach us the futility of buying too cheap or too dearly.

What Is The Engineer To Do?

The question arises: Since it is difficult to assign a quantitative significance to reliability, how can this characteristic be evaluated and how are we to judge and choose between two or more pieces of equipment, ostensibly designed to perform the same function with the same degree of satisfaction? Can we assign any specific value to differences—claimed or real—which distinguished between two methods of accomplishing a given function? And before I answer this question, let me remind the reader that in his private life he is constantly doing just that. He is evaluating intangibles each time he buys a house, a car, a suit or even a tie. He is choosing without the benefit of quantitative analysis when he selects furniture for his living room, the resort for his vacation or the career to which he will devote his life.

Then why does the engineer shy away from such evaluations in the exercise of his profession? Is it because he has heard it proclaimed that engineering is an exact science and that he wishes to pay at least lip service to that outworn cliché? Or is it because he does not always wish to take the responsibility of exercising his judgment, lest he be accused of dealing in hunches, unsupported by solid facts?

We engineers are faced with constant decisions, required to justify our every action, destined to make numberless errors and beset with difficulties at every turn. How easy, then, to surrender our right to make these decisions to a tabulation of symbols inscribed in black ink on an innocent piece of white paper. To make the mute testimony of numbers responsible for all our conclusions. To blame the errors on some mysterious inconsistency between these numbers and the actual facts. And to shrug off the difficulties onto whatever or whoever lacks the protection of other numbers, other equations and other dry statistics.

But I refuse to accept this as an explanation of the common preference for a coldblooded evaluation of dollars and Btu's, with little or no regard for the evaluation of less tangible equipment characteristics. I prefer to believe that if some engineers fail to take into account or even to recognize these less tangible characteristics, it is merely because they are not adequately equipped for this task. It is because those of us whose duty it is to educate others in this recognition process have, in some cases, failed to accomplish what we had set out to do. And if the thoughts expressed on these pages have in some measure served to focus our attention on some important factors affecting an evaluation of reliability, amends will have been made—at least to some extent.

I can hear someone say that I have not answered all the questions that I have raised. Decidedly and knowingly I have not, for I had set myself the task of exploring the little known and seldom discussed phases of these problems and I had made it my responsibility to ask these questions, not to answer them.

Mines Bureau Reports on Cost Studies for Removing Sulfur Dioxide

Estimated costs for building and operating various types of equipment to remove harmful sulfur dioxide from flue gases of coal-burning power plants in the United States were listed recently by the Bureau of Mines, Department of the Interior, as part of a study for the Public Health Service under the national air-pollution-prevention program.

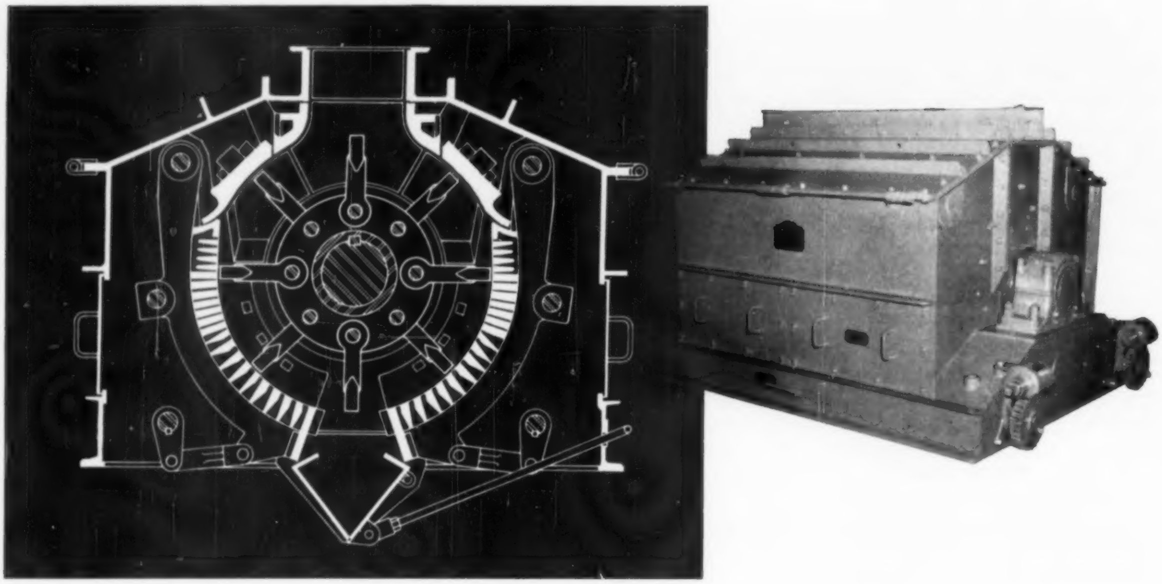
The study centered on power plants of 120,000-kw capacity burning an estimated 475,000 tons of coal a year. Costs of installing scrubbing equipment to curb sulfur dioxide would range from $1.75 million to $5 million, depending on the gas-cleaning process used. Operating costs were estimated to range from $1.40 to $2.20 per ton of coal consumed. The operating cost would be lower if marketable by-products were recovered from the furnace gases.

Bureau researchers point out, however, that credit for products obtained from the scrubbers "should be allowed with extreme caution," because the materials—ammonium sulfate, sulfur, and sulfuric acid—might saturate the market and force prices down.

Three different liquid processes for removing sulfur dioxide from flue gases were listed by the Bureau: the limestone, ammonia, and the sodium sulfite method. Without considering credit for by-products, the Bureau said that capital investment and operating costs were lowest for the limestone process.

A publication describing the study, written by J. H. Field, L. W. Brunn, W. P. Haynes, and H. E. Benson, points out that the rising consumption of fuels with relatively high sulfur content, particularly in heavily populated areas, has caused increased concern over atmospheric pollution by sulfur dioxide.

In studying the problem, the Federal researchers found that many elements must be considered, including the amount of allowable sulfur dioxide that power plants are permitted to discharge, the sulfur content of the fuel used, and the varying prices for by-products.



The advisability of installing an air preheater on an industrial boiler is given a close scrutiny. Two specific case histories are advanced on which studies were conducted and the principal factors determining selection and installation of an air preheater were identified.

The Economics of Air Preheat on Industrial Boilers*

By CHARLES L. BROWN†

The Air Preheater Corp.

DETERMINING factors in the evaluation of heat recovery equipment are the fuel cost, amount of heat recovery, equipment cost and equipment installation.

The regenerative air preheater performance discussed in this paper is representative of the average installation, and its evaluation clearly presents the application of the determining factors. Performance data for this particular installation show the payout time for the preheater with various fuel costs as 1.64 years, 1.3 years, 1.08 years and 0.92 years, which result in a 61.3 per cent, 72.2 per cent, 93.0 per cent and 108.7 per cent return of capital invested. These returns and payout times were based on an increase in boiler efficiency of approximately 10 per cent.

The boiler in question was originally purchased by the Southern Kraft Division of International Paper Company, with provisions for firing only fuel oil. The possibility of an anticipated shortage of fuel oil caused the boiler to be adapted for firing pulverized coal at the start of World War II. However, the need to fire pulverized coal was never realized, since the fuel oil supply was never interrupted. The pulverizers were only operated for a period of 4 hr, just to insure their operation. The boiler continued to operate with fuel oil until 1956. It was at this time that the cost of oil was more expensive than the cost of coal. To help reduce the operating costs, it was decided to fire coal and when necessary to supplement the firing with fuel oil.

Fuel Costs

Fuel costs have been increasing constantly. This presents an important consideration when evaluating heat recovery equipment. While capital charges for the equipment are fixed, the important factor of fuel cost is the one variable. Therefore, to approach a more realistic procedure in establishing the economic justification of equipment, an average fuel cost based on one-half the expected life of the equipment should be used.

Fuel cost curves for coal, oil and natural gas are shown in Figs. 1, 2 and 3. The trend line on each curve represents the more realistic fuel costs figure. To establish the fuel costs for evaluation purposes, a fair approximation would be to take the average rate of rise from the preceding ten or twenty years, and project them to the future ten or twenty years, depending on the capitalized life of the equipment. That is the ap-

* Presented before the American Power Conference, Chicago, Ill., Mar. 31, April 1, 2, 1959.

† Technical Consultant.

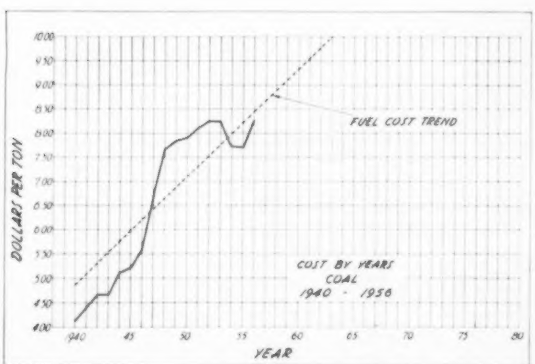


Fig. 1—Cost by years—coal

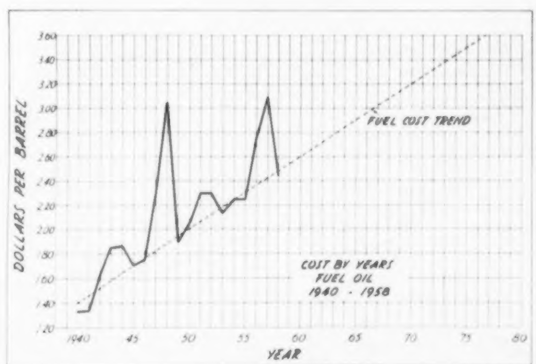


Fig. 2—Cost by years—fuel oil

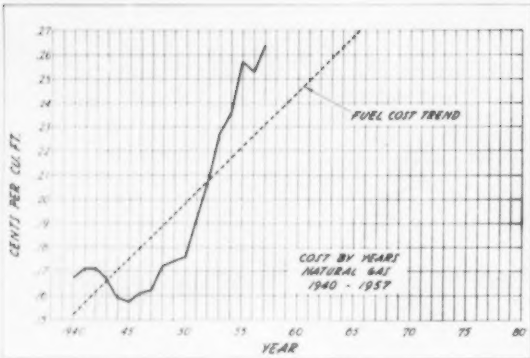


Fig. 3—Cost by years—natural gas

proach that International Paper Company's Panama City Mill used to determine the economics of a package Ljungstrom Air Preheater, when it was decided to rebuild one of its power boilers.

In 1955 plans were made to rebuild the boiler and convert to coal for primary firing. Based on averages, the fuel cost for the coming ten years was projected and one-half the rise of the trend line was used for preliminary evaluation purposes. This amounted to $9.32/ton or approximately $0.35/million Btu's.

Installation Costs

Installation costs in this particular application were increased by repositioning of equipment. In rebuilding the boiler a dust collector was necessary. By the inclusion of the collector, the normal boiler outlet had to be repositioned. Fig. 4 shows the layout of the boiler, air heater and collector. If the collector was to be used without an air heater, the outlet would have been moved from Point "A" to Point "B." With the inclusion of the air heater, the new boiler outlet was lowered from Point "A" to Point "C." Since the gas side of the air heater acts as a duct, there was very little additional gas ducting necessary over the outlet first anticipated.

The air duct and the F.D. fan presented a different situation. In the event an air heater was not used, the F.D. fan and existing ducts would have sufficed. By the inclusion of an air heater, the F.D. fan could not be used in its former location, namely, on the level beneath the boiler. To effect a more suitable duct layout, it was necessary to change the location of the F.D. fan, Fig. 5. It was also necessary to revamp the existing F.D. fan, since the original fan could not handle the increased air pressure loss through the air heater as the I.D. fan could. Table V shows the costs of the air heater, F.D. fan, and duct work. From the figures, the "D" and "E" basis of the total cost of the air heater and the changes necessary to accommodate the air heater amounted to $33,988. The total cost including the dust collector was $48,752.

In Table V the total man-hours required for the installation of the air heater, as well as the man-hours required for moving the F.D. fan and the erection of the duct are shown. One point of particular import is the number of man-hours required for the air heater above. The Air Preheater Corporation estimated it would take 195 man-hours to erect, however, it actually took 600 hr. The extra number of hours were necessary since the air heater was shipped as a package, that is, completely assembled, and extra time was required to snake the air heater past and around existing pieces of equipment.

This increase in man-hours is generally true when rebuilding a boiler by incorporating an air heater. The figures normally quoted are to position the air heater

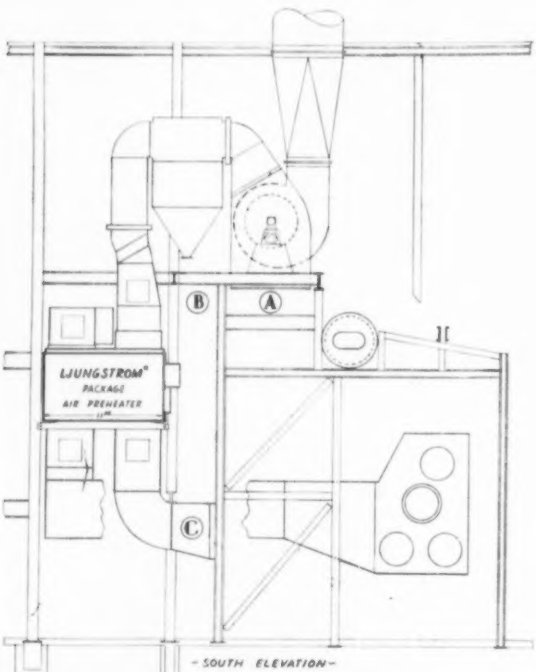


Fig. 4—General layout No. 4 power boiler

TABLE I—ANALYSIS OF FUELS TO BE BURNED

	Oil	Pulv. Coal
S	1.16	1.33
H_2	10.33	4.75
C	87.87	73.82
N_2	0.14	1.33
O_2	0.50	5.13
Moisture	...	5.00
Ash	...	8.64
Btu	18,400 Btu/lb	13,319 Btu/lb

TABLE II—TEST RESULTS WITH AND WITHOUT AIR HEATER

Case	One	Two	Three	Four
Fuel	Oil	Oil	Pulv. coal	Pulv. coal
Steamflow lb/hr	115,146	116,000	85,000	85,000
Steam temperature	612 F	615 F	610 F	610 F
Feedwater temperature	337 F	340 F	340 F	340 F
Ambient air	93 F	128 F	95 F	95 F
Gas temp. lv. Blr.	726 F	777 F	728 F	728 F
Air temp. lv. A. H.	...	651 F	...	600 F
Gas temp. lv. A. H.	...	370 F	...	335 F
Corr. gas temp. lv. A. H.	...	350 F	...	315 F

NOTE—Case 1 and Case 3—no air heater; Case 2 and Case 4—air heater

TABLE III—CALCULATION RESULTS OF TEST RUNS, TABLE II

Case	One	Two	Three	Four
Air wt. lv. A. H. lb/hr	127,500	114,000	92,200	81,400
Air wt. to A. H. lb/hr	...	...	...	...
Gas wt. Ent. A. H. lb/hr	146,800	131,000	114,500	101,000
Gas wt. lv. A. H. lb/hr	...	...	...	...
Ambient air	93	128	95	95
Air temp. lv. A. H. °F	...	651	...	600
Gas temp. ent. A. H. °F	726	777	728	728
Gas temp. lv. A. H. uncor.	...	320	...	335
Gas temp. lv. A. H. cor.	...	350	...	315
Fuel rate	8350	7450	8630	7620
Boiler eff.	73.56	84.85	73.90	83.75

TABLE IV—COST BREAKDOWN FOR AIR HEATER INCLUSION

OPERATING COST OF THE AIR HEATER

Figures based on anticipated APL (air pressure loss) and DL (draft loss) of air heater

@ 116,000 lb/hr load with oil firing
APL 1.35" W.G. DL 2.65" W.G.

@ 85,000 lb/hr load with P.C. firing
APL 0.95"W.G. DL 1.65"W.G.

Since evaluation is based on average load use figure for 85,000 lb/hr load and increase loses by 25 per cent

$\therefore$ APL = 0.95 × 1.25 = 1.20"W.G.
DL = 1.65 × 1.25 = 2.10"W.G.

POWER COSTS

Additional power reqd. because of air heater

$$\text{F.D.-fan HP} \quad \frac{0.000157 \times (93{,}500/60) \times 13.86 \times 1.20}{0.70} = 5.82$$

$$\text{I.D.-fan HP} \quad \frac{0.000157 \times (113{,}500/60) \times 19.87 \times 2.10}{0.60} = 20.65$$

	26.47
Preheater drive	2.
	28.47

KW = 28.47 HP × 0.746 KW/HP = 21.25 = 21.3 KW
21.3 KW × 80.00 hr × 0.01/KW hr—$1704/yr

and connect the duct work, oil piping and wiring the equipment. It would be impossible to account for all the obstructions that might increase the number of man-hours during the preliminary consideration. In this particular instance, there was a considerable limitation of space because of the close proximity of an adjacent boiler, which resulted in higher than normal man-hours to position the air heater.

Operating Tests

After more than a year's operation, it was decided to test the boiler with the air heaters as compared with previous test data. Some time previous to the installation of the air heater a test with oil firing was performed. The data for this test is recorded as Case 1 in Table II. Although the boiler would not operate at a 116,000 lb per hr load when firing only oil, this was performed to give a basis when a test was performed, when firing pulverized coal. The test figures for 116,000 lb per hr when firing oil with the air heater are tabulated as Case II in Table II.

When the operating data at the plant was reviewed, it showed that the preceding yearly steam load was 85,000 lb per hr and pulverized coal was used exclusively. Therefore, it was decided to base the evaluation on this average load condition and fuel.

A test was then performed at the above conditions and the results are tabulated as Case 4 in Table II. This test included the air heater.

As was mentioned the anticipated need for firing pulverized coal never materialized. Consequently, test data for firing coal without an air heater was unobtainable.

To correlate the performance with and without an air heater for coal firing the same considerations were given as the relationship when firing oil. To realize this relationship, it was necessary to make assumptions. These assumptions were the steam conditions, feedwater temperature and gas temperature would be the same without the air heater, as they were with the air heater. These assumptions were necessary to calculate the expected boiler performance.

The results of the calculations give good correlation when compared to the data calculated when firing oil. When comparing the oil figures at the 116,000 lb per hr load, we find that there is a 9.49 per cent increase in boiler efficiency which results in a 10.78 per cent fuel savings. When firing pulverized coal at 85,000 lb per hr steam load, we note a 9.73 per cent increase which results in an 11.67 per cent fuel savings. These figures are shown in Table III.

Costs and Savings

In establishing the dollar savings in the evaluation the 85,000 lb per hr steam load was used for the yearly operation of 8,000 hr.

TABLE V—TOTAL COST OF AIR HEATER—D & E (DESIGN AND ERECTION)

Air heater*	1420 man-hours	$22,635	labor and material
F.D. fan	812 man-hours	$ 2,939	labor and material
Duct work	1840 man-hours	8,424	labor and material
	4072 man-hours	$33,998	labor and material
Fixed charges 12.5 per cent of D & E			$4,249.75
Operating cost			1,704.00
			$6,053.75

* Includes air heater, support steel, electrical conn., insulation and miscellaneous.

TABLE VII—SUMMARY OF NET SAVINGS, PAYOUT TIME, PER CENT RETURN

Fuel cost	0.25	0.30	0.35	0.40
Gross	$26,890	$32,280	$37,650	$43,000
Oper. costs	6,054	6,054	6,054	6,054
Net savings	$20,836	$26,226	$31,596	$36,946

Using 35c fuel
Total cost of air heater, $33,998
Net fuel savings, $31,596
Payout time, 1.08 years
Return on money, 93%
Payout for various fuels

0.25	0.30	0.40
1.64 years	1.3 years	0.92 years

Return on money, %

61.3	77.2	108.7

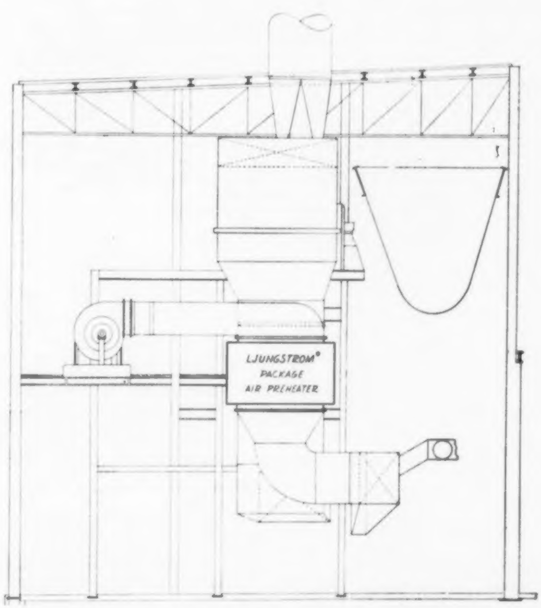


Fig. 5—West elevation

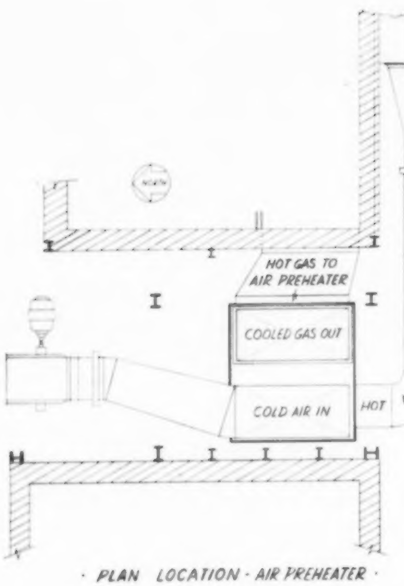


Fig. 6—Plan location—air heater

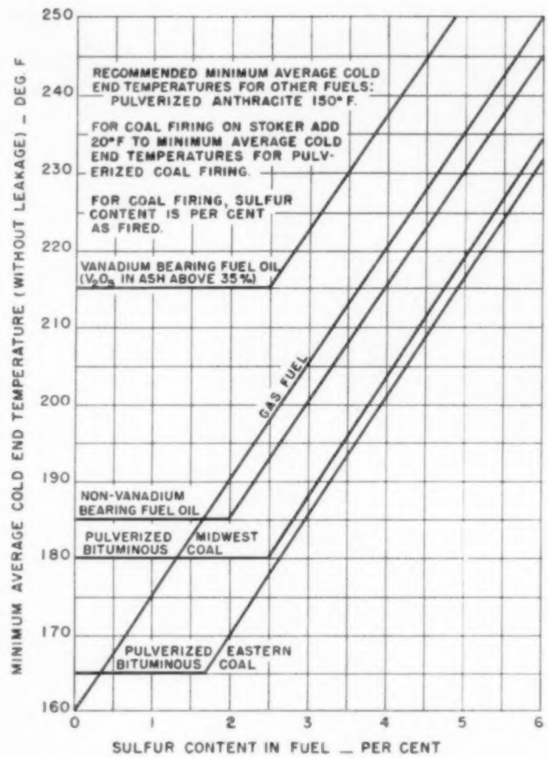


Fig. 7—Cold end temperature guide for selection and operation of Ljungstrom regenerative type air preheaters

In determining the operating costs of the air heater, additional tolerances were included to be as conservative as possible, Table IV. The total cost of the air heater, erection, duct work, are covered in Table V.

Table VI shows the evaluation based on the average fuel savings and various fuel costs that can normally be expected. In Table VII we have a summary of the net savings for the various fuel costs, as well as a tabulation of payout time and per cent return of investment.

With reference to the fuel costs, it should be pointed out that in this particular case, the type of fuel is of little concerr. when establishing the payout time or per

TABLE VI—EVALUATION OF SAVINGS, CHARGES OF AIR HEATER INSTALLATION

Based on Fuel Cost of \$9.32/ton from Fuel Cost Trend

Fuel saved—1010 lb/hr
Hours oper./yr—8000
Btu of fuel—13,319
Fuel cost = \$0.35/10^6 Btu
Gross fuel savings
1010 lb/hr × 13,319 Btu/hr × 8000 hr/yr × 0.35/10^6 Btu = \$37,650

Fuel savings based on 25c, 30c—40c/10^6 Btu-fuel costs
25c . . . . . . \$26,890 per year
30c . . . . . . 32,280 per year
35c . . . . . . 37,650 per year
40c . . . . . . 43,000 per year

Fixed charges = 12.5% of D & E (Design and Engineering) price of air heater
D & E price = \$33,998
Operating cost = \$1704
Fixed charge = \$4,249.75
Total oper. cost = \$6053.75

TABLE VIII—FORMULAE FOR MAKING EFFICIENCY CALCULATIONS

Based on 10,000 Btu

Theo. Air lb/100 lb

Oil
$S = 1.16 \times 4.32 = 5.02$
$H_2 = 10.33 \times 34.35 = 355.50$
$C = 87.87 \times 11.54 = 1015.00$
Total 1375.52
$O_2 = 0.50 \times 4.32$ 2.16
1373.36
$\frac{1373.36}{184.00} = 7.46$ lb air/10 KB

P. C. lb/100 lb
$S = 1.33 \times 4.32 = 5.74$
$H_2 = 4.75 \times 34.35 = 163.10$
$C = 73.82 \times 11.54 = 852.00$
Total 1020.84
$O_2 = 5.13 \times 4.32$ 22.16
998.68
$\frac{998.68}{133.19} = 7.50$ lb air/10 KB

Water in fuel $\frac{9 \times H_2 \times \text{moisture} \times 100}{\text{Btu}}$

Pounds fuel per 10-KB = $\frac{10{,}000}{\text{Btu/lb}}$

Actual dry air—total air × theo. air
Moisture in air 3/10 KB
$\frac{\text{lb moisture in air}}{\text{lb dry air}} \times$ actual air/10 KB
$\frac{\text{lb moisture in air}}{\text{lb dry air}} = 0.013$ lb/10 KB

Additional moisture (steam automization) = 0.04 lb/10 KB

Dry gas $\frac{\text{lb}}{10/\text{KB}}$ = total wet gas $\frac{\text{lb}}{10/\text{KB}}$ − total H_2O in wet gas $\frac{\text{lb}}{10/\text{KB}}$

Efficiency

Loss due to dry gas $\frac{0.24 \times \text{dry gas} \times \text{gas temp. lv.} - \text{air ent.}}{100} =$ %

Loss due to comb. of H_2 $\frac{2 \times 0.24 \times \text{gas temp. lv.} - \text{air ent.}}{100} + \frac{\text{latent heat}}{100}(1000)$

Radiation and unaccounted (assumed) oil 4.00% P. C. 4.50
Output = wt. steam × h sh. steam—h F.W.
Input = $\frac{\text{output}}{\text{eff.}}$
Fuel rate = $\frac{\text{input}}{\text{Btu/lb fuel}}$

cent return of money invested. For any other application, one of the factors that would have a bearing on the payout time would be the amount of recovery that the air heater could tolerate with respect to protection for corrosion. Each fuel has its own limitation. These limitations are exaggerated by the sulfur content of the fuel. In Fig. 7, a reproduction of *Ljungstrom Metal Temperature Control Guide* is shown. This guide has been developed, after much operating exerience with various fuels with various sulfur contents. This guide was used to determine the permissible exit gas temperature leaving the air heater, so that the most recovery could be realized, and yet, not require protection. Therefore, the fuel savings or the increase in boiler efficiency can be affected by the type of fuel fired, as well as the amount of sulfur the fuel contains. However, if the temperature of the gas leaving the air heater is high enough to prevent the approach to the dewpoint, then the fuel costs based on that exit temperature will be the only consideration necessary.

Acknowledgment

The writer wishes to gratefully acknowledge the cooperation extended by the personnel of The Southern Kraft Division of International Paper Company, Mobile, Ala. and particularly the power plant personnel of the Panama City Mill.

Tar, Transported by Pipeline, Primary Fuel for Power Plant

How HiVis, or tar pitch, a petroleum product of high viscosity, can be transported by pipelines heated by the thermal electric principle was described at the recently concluded Convention of the American Society of Civil Engineers in Cleveland, Ohio, May 4–7, 1959.

A. G. Purdue, Fluid Systems, Inc., New Haven, Conn., told the engineers that the new 100,000-kw Sur Station of the Puerto Rico Water Resources Authority, at Guayanilla, P. R., is using HiVis in its generating plant as a primary fuel, and it is being supplied by heated pipeline from a nearby refinery.

The high-viscosity material, which is all but unmanageable by the usual techniques for handling and storage, represents a considerable fraction of each barrel of crude oil—20 to 30 per cent, depending upon the source of crude and the fractionation process, Mr. Purdue said.

While its physical properties cannot be precisely specified, a liquefication temperature of about 250 F is typical, and the material usually flows readily at about 350 F. Only at still high temperatures, in the vicinity of 450 F, can it be burned.

The significant property of HiVis is that it is a good fuel, and on a pound-for-pound basis the heating value is not inferior to that of bunker oils in general use. The problem is to deliver HiVis to the burner nozzles in usable condition.

The problem for the Puerto Rican generating plant was solved by installing a thermal electric pipeline, a recent development for heated pipeline transportation of highly viscous materials.

The thermal electric principle is to use the reactance of the pipe itself to transform electrical energy into heat in a manner which can be closely regulated. By maintaining a constant temperature along the length of pipe, thermal exchanges between the fluid and the pipe wall are minimized, and flow conditions and load upon the pumping station are held constant.

From an engineering point of view, he added, further advantages of the principle become apparent, one of which is that standard schedule piping can be heated with readily available values of currents and voltages.

"It is a safe prediction," Mr. Purdue stated, "that the demand for thermally generated electric power will continue its present rise into the next decade and beyond.

"The most optimistic forecasts for the future of synthetic energy sources only give further reason to believe that natural petroleum fuels will carry the base loads of the world's energy requirements for years to come.

"This predictable increase, coupled with changing world conditions which may result in a redistribution of petroleum reserves, makes it imperative that ways be found for getting the maximum energy usage out of each barrel of crude produced."

CEI To Spend 200 Million on Construction in 5 Years

To accommodate the growing power needs of consumers of the 138 communities in northeast Ohio which it serves, the Cleveland Electric Illumination Company has a construction budget of $200,000,000 for the next five years, the American Society of Civil Engineers was told at its May Convention in Cleveland.

Construction expenditures for 1958 amounted to $56,000,000, Russell G. Stewart, senior engineer of the company's civil engineering department, told the meeting of ASCE engineers.

For 1959, the company has a construction budget of $38,000,000, Mr. Stewart revealed.

The company's power system, which serves a 1700-mile area extending for 100 miles along the southern shore of Lake Erie, with Cleveland as its hub, includes four interconnected power stations with a net generating capability of 1,909,000 kw.

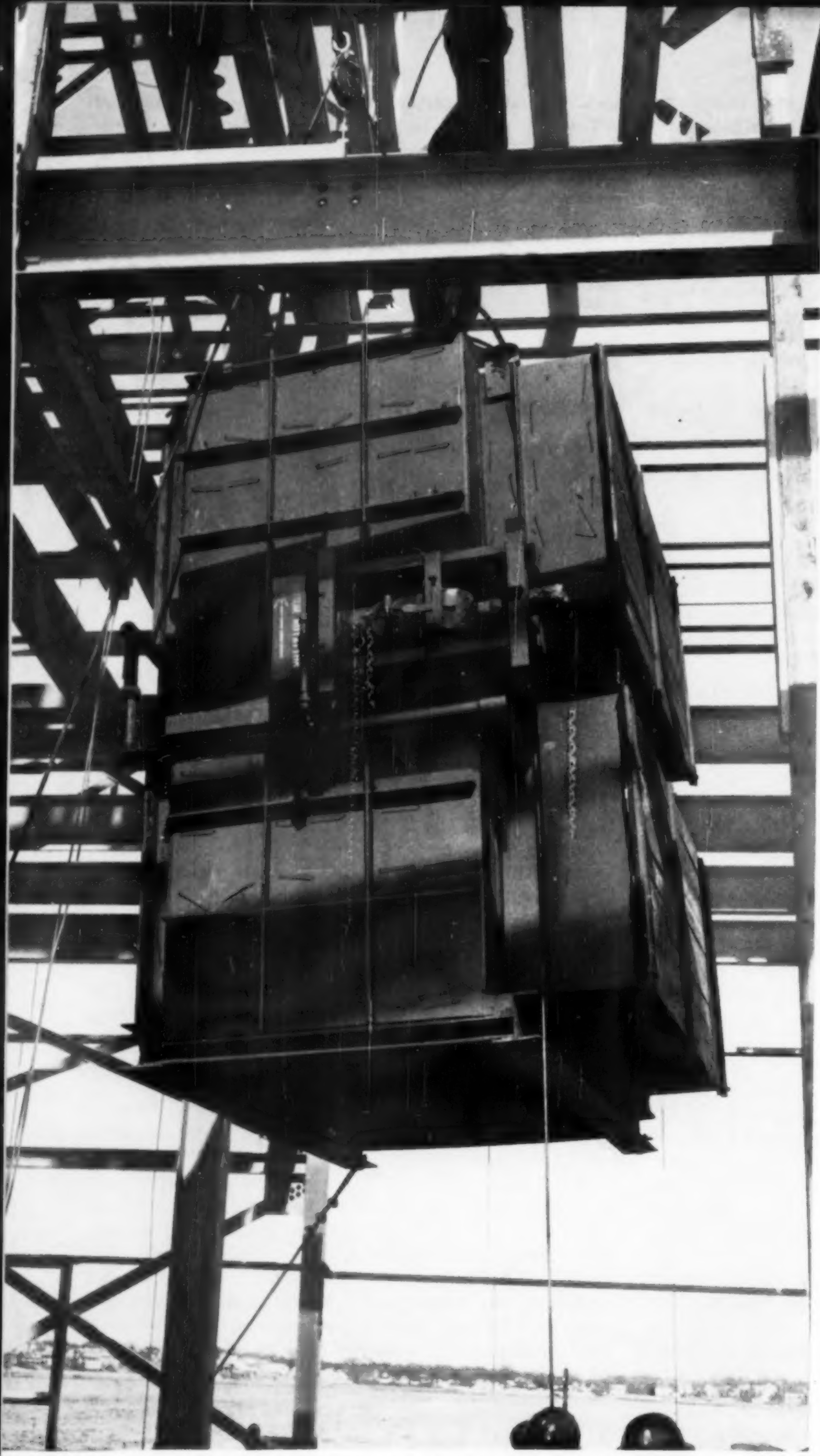
This capability will be increased to 2,151,000 kw with the installation of a new generator now under construction at the Avon station.

Mr. Stewart appeared before a Power Division session to outline the layout procedure used in designing a large single unit addition to an existing steam generating station which he said resulted in (*a*) a building of only 15 cu ft per kw hr of generating capacity, (*b*) a saving in design time, and (*c*) a minimum of field and fabricating changes.

He said the layout procedure was first formalized and used on Eastlake No. 4 addition to an existing plant site which had been developed previously. However, he used examples and slides taken from CEI's experience on a recently completed addition to its power station at Ashtabula. That project, he said, cost $32,000,000.

Mr. Stewart noted that one of the problems typical of all power house projects where structural steel is used is the lag between the time the decision is made to build the project, and that day on which actual erection of structural steel is started.

He said that the development of a formalized layout procedure outline, which he discussed at the Convention meeting, solved this problem to a great degree.



Complete and ready to run, Package Air Preheater is lowered through steelwork of new power station at Braintree, Mass. Installation at Braintree Electric Light Dept. uses largest available package preheater, with a diameter of approximately 12'. Fitted to a 130,000 lb per hr boiler, this Package Air Preheater will boost combustion air temperature by about 420°F with heat recovered from stack gas.

PACKAGE AIR PREHEATER

gives twofold economy at Braintree's new power station

PACKAGE DESIGN FACILITATES INSTALLATION; FUEL SAVINGS TO WRITE OFF COST IN 2 YEARS.

Braintree, Mass., has achieved an economic double-header with the Air Preheater in their new power station:

1. Initial saving: The Package Air Preheater, shown above, was delivered as a completely preassembled unit. All it needs is gas ducts and a power line and it's ready to work—installed at a fraction of the time and cost required for conventional units.

2. Long-term savings: Records prove that Braintree's Package Air Preheater can pay for itself—just on fuel savings alone—within two years.

Package design gives you these advantages on boilers as small as 25,000 pounds of steam per hour—or as large as 250,000 lbs per hr. And a Package Air Preheater is one of the surest ways to reduce fuel consumption: you cut your fuel bill 1% with every 45-50°F increase in preheated air temperature.

Get all the facts. Write today for your copy of the free 14-page booklet describing the multiple savings you get with a Package Air Preheater.

THE AIR PREHEATER CORPORATION

60 East 42nd Street, New York 17, N. Y.

Abstracts From the Technical Press—Abroad and Domestic

(Drawn from the Monthly Technical Bulletin, International Combustion Ltd., London, W.C. 1)

Fuels: Sources, Properties and Preparation

Further Studies on Weathering of Coal. J. Bandopadhyay, D. C. Mitra, J. M. Sanyal, N. Das Gupta and A. Lahiri. *Coke & Gas* 1959, **21** (Mar.) 99–104.

The effect of weathering (oxidation) of various Indian coals on coke strength was studied. It was found that an increase of capacity moisture with oxidation served as a better guide to deterioration of coke strength than other tests.

Some Measurements of Dynamic Mechanical Properties of Coal. F. J. Hiorns. *Mechanical Properties of Non-Metallic Brittle Materials. Butterworth Scientific Publication*, pp. 259–68.

Methods of measuring Young's modulus and internal friction in coal are described. The effect of moisture and temperature on these properties has been studied. The practical application of these studies to grinding processes with simultaneous drying by heating is described.

The Heat of Wetting of Coals. M. S. Iyengar and A. Lahiri. *Brennst-Chemie* 1959, **40** (Feb.) 45–50 (In German).

Based on detailed studies of Indian coals it is claimed that the heat of wetting in methanol is a measure of the reactive oxygen groups present in the coal rather than of its surface. This parameter is useful for predicting ignitibility, behavior during carbonization, grindability and other characteristics.

Heat: Cycles and Transmission

Heat Transfer. E. R. G. Eckert, J. P. Hartnett and T. F. Irvine. *Ind. Engng. Chem.* 1959, **51** Pt. II (Mar.) 543–65.

This review of literature of 1958 is divided into the following chapters: 1. Conduction; 2. Channel flow; 3. Boundary layer flow; 4. Flow with separated regions; 5. Transfer mechanism; 6. Natural convection; 7. Convection from rotating surfaces; 8. Transpiration and mass transfer cooling; 9. Change of phase; 10. Radiation; 11. Liquid metals; 12. Heat transfer applications.

Thermodynamics. J. M. Smith and G. M. Brown. *Ind. Engng. Chem.* 1959, **51** Pt. II (Mar.) 472–80.

The review of literature published during 1958.

Temperature Distribution and Heat Transfer from Radiant Flames to Finned Tubes. K. Becker. *Energie* 1959, **11** (Feb.) 59–71 (In German).

A detailed mathematical analysis is presented which shows that finned tubes are specially suitable for radiant heat transfer and are superior to plain tubes. The analysis is carried out for fins of constant and of wedge-shaped cross sections.

Steam Generation and Power Production

Flow of Fluids. M. Weintraub. *Ind. Engng. Chem.* 1959, **51** Pt. II (Mar.) 362–9.

The review of literature published during 1958.

Fluid Dynamics. A. K. Oppenheim, C. V. Sterling, C. A. Sleicher and R. A. Stern. *Ind. Engng. Chem.* 1959, **51** Pt. II (Mar.) 437–52.

The review of literature published during 1958.

The Work of the Boiler Availability Committee. F. W. Lawton, H. E. Crossley, D. C. Gunn, W. F. Harlow, J. R. Jenkinson and W. G. Marskell. *J. Inst. Fuel* 1959, **32** (Mar.) 120–43.

The first paper is a general introduction, the second deals with early, recent and future work of the committee (oil firing), the third with the occurrence and the amount of corrosive substances in flue gases and the use of additives, the fourth and fifth with the causes of corrosion, and the sixth with corrosion and deposit formation in stoker, pulverized fuel and oil fired boilers.

Two Stage Evaporation. L. Stanisavlievici. *Mitt. V.G.B.* No. 58 1959, (Feb.) 15–21 (In German).

An analysis of the salt concentrations in the water and steam of boilers with two stage evaporation has shown that the advantages of purer steam claimed for these plants is not confirmed by theoretical considerations and causes, in addition, difficulties in operation.

The Time Required for Starting Up Drum-Type Boilers at High Pressure. V. G. Chakrigin. *Teploenergetika* 1959, **6** (Mar.) 35–9 (In Russian).

An analysis has been carried out to establish the temperature field in the main boiler drum from the time of starting the fire. Recommendations are given for determining the rate of starting up of high pressure boilers.

Temperature Conditions of the Metal Used for Evaporating Tubes in Forced Flow Boilers. Z. L. Miropolsky. *Teploenergetika* 1959, **6** (Mar.) 40–4 (In Russian).

The temperature conditions particular to the metal used for evaporating tubes are considered. Methods of determining wall temperatures experimentally are reviewed.

Fuel Firing

Some Characteristics of Pulverized Tilting, Slotted Burners. A. L. Bichkovsky. *Teploenergetika* 1959, **6** (Mar.) 45–9 (In Russian).

Experimental studies are presented on 2 types of burners carried out to assess their resistance and heat loss as a function of their design and of operating conditions.

Calculation of Slagging Furnaces. A. Zinzen. *BWK* 1959, **11** (Mar.) 117–9 (In German).

A diagram has been developed for showing the relationship between: 1. Heat exchange between flame and wall; 2. Heat transfer through the wall; 3. Difference between theoretical combustion temperature and actual flame temperature. It also permits the calculation of the size of a slagging furnace for given conditions and its performance under different conditions.

Water-Side Corrosion and Water Treatment

Water Treatment Part II. R. H. Marks. *Power* 1959, **103** (Mar.) 65–88.

The second part of this review deals with: 1. Treatment choice; 2. Objectives of feedwater treatment; 3. Boiler blowdown; 4. Internal treatment; 5. Boiler pressure and treatment choice; 6. Feedwater treatment for high pressure and once-through boilers; 7. Cooling water treatment; 8. Process water treatment; 9. Automatic controls.

Recent Research on Boiler Tube Corrosion. E. C. Potter. *Chem. and Ind.* 1959, (Mar. 7) 308–14.

The advantages of statistical approach to the problem of water-side corrosion of boiler tubes are described, which have shown that one-third of all power stations and one-quarter of all boilers operating above 350 psi suffered corrosion by the end of 1955; on average, power stations contain 6

boilers of which 4 are affected. Tables give data on time variation of corrosion, newly corroded boilers year by year and the relation between dissolved oxygen and corrosion. The mechanistic approach to corrosion is explained and the several theories of the mechanism of corrosion are discussed. The experimental approach to the problems describes some of the studies undertaken on the I.C. experimental boiler and some of the results obtained so far.

Operational Supervision of Feedwater and Cooling Water. W. Töller. *Mitt. V.G.B.* No. 58 1959, (Feb.) 21–5 (In German).

The supervision needed to guarantee feedwater of the required purity depends on: 1. Raw water properties; 2. Kind and size of treatment; 3. Design of boiler plant; 4. Load conditions; 5. Presence of recording analyzers; 6. Personnel questions. The frequency of analysis of raw, feed, boiler and cooling water by the plant personnel and the laboratory proposed for the new German specifications are discussed.

Investigations of the Solubility of Salts in Water Vapor with Supercritical Parameters. M. A. Styrikovh and L. K. Khoklov. *Teploenergetika* 1957, (Feb.) 3–7 (In Russian). D.S. I.R. Translation CTS. 592.

A method of studying the solubility of calcium sulfate, chloride and carbonate in steam at 300 m. by means of radioactive isotopes is described; the method was also used to study the solubility of sodium chloride and sulfate. The results are presented in graphs. The application of the findings to the design and operation of supercritical pressure boilers and the feedwater treatment required for these boilers are discussed.

The Fouling of Strongly Basic Anion Exchangers by Humic Acid. A. L. Wilson. *Mitt. V.G.B.* No. 58 1959, (Feb.) 26–9 (In German).

Strongly basic anion exchangers installed in mixed bed feedwater treatment plants may absorb humic acids which reduce their capacity. They must then be treated with a solution of 2 mole NaCl/1 and 1.5 mole NaOH/1.

Gas-Side Corrosion and Deposits

The Chemical Behavior of Sodium and Potassium Pyrosulfates. K. Wickert. *BWK* 1959, **11** (Mar.) 110–3 (In German).

The temperature range of formation and decomposition of alkaline pyrosulfates and the melting point of pure pyrosulfates and their mixtures have been determined. The temperature-depending occurrence of partial melts in some of these mixtures has been studied. Solidification phenomena of pyrosulfates mixtures and corrosion caused by these substances have been measured. The contribution of pyrosulfates to boiler and gas turbine fouling and corrosion is discussed.

Flue Gas, Ash and Dust

Catalytic Oxidation of Sulfur Dioxide at Low Concentrations. D. H. Napier and M. H. Stone. *J. Appl. Chem.* 1958, **8** (Dec.) 781–6.

A catalytic process for oxidizing SO_2 to SO_3 employing four different V_2O_3 catalysts is described. This conversion would be the first step in removing sulfur oxides from flue gases. The second step would be the removal of SO_3 as ammonium sulfate or sulfuric acid.

The Measurements of Smoke Emission. R. Jackson. *Steam Engr.* 1959, **28** (Mar.) 187–92.

This review is divided into: 1. Measurement of dark smoke; 2. The Ringelmann chart; 3. Method of use of chart; 4. Other methods of assessing darkness of smoke plumes; 5. Accuracy of measurement of darkness of smoke emission; 6. Obscuration type smoke meters.

Particle Size and Separation Efficiency. B. Mansson. *Tekn. Tidskr.* 1959, **89** (Jan. 30) 87–92 (In Swedish).

In a review of factors which affect calculations of the overall efficiency of dynamic separators, the author discusses dust-separator characteristic separation curves, influence of gas temperature, dust concentration and presence of secondary separators on separation efficiency, and effect of cyclone size and entry velocity on efficiency.

From *C.E.G.B. Digest* 1959, **11** (Feb. 28) 499.

Heat Recovery Plant

The Use of Hydrodynamic Models for the Improvement of Heat Exchangers. P. Dumez. *Flamme et Thermique* 1959, **10** (Jan.) 11–24 (In French).

The first part deals with the laws of hydraulic analogues and similarity and their application to the study of heat exchangers. The second part describes the study of flow conditions in a tubular air preheater in a model and the improvement achieved by this means (an increase of efficiency from 71 to 87 per cent) in an actual case.

The Influence of Spray Desuperheating for the Control of Steam Temperature on the Specific Heat Rate of the Turbine Plant. S. Kriese. *Mitt. V.G.B.* No. 58 1959, (Feb.) 12–4 (In German).

The use of spray desuperheaters for the control of the superheated and reheated steam temperatures causes an increase in specific heat rate of the turbine, but this increase remains below 1 per cent even in extreme cases.

The Mean Temperature Difference in Hairpin Heat Exchangers. H. Hausenblas. *BWK* 1959, **11** (Mar.) 114–6 (In German).

Equations are developed for calculating the mean effective temperature difference in hairpin heat exchangers. It is shown that this difference is always lower than in counterflow heat exchangers and that for the same entry and exit temperatures and the same heat transfer coefficient the hairpin exchanger requires more heat transfer surface than the counterflow exchanger.

Power Generation and Power Plant

Combined Gas-Steam Turbine Cycle Offers Plant Savings. I. J. Karassik. *Elect. World* 1959, **151** (Mar. 9) 60–1.

One of the drawbacks of double reheating is the large diameter of pipelines required for the second reheat circuit. To meet this objection, it is proposed to install the second reheater next to the turbine, supplying it with compressed air from a gas turbine driven compressor and fuel and using the exhaust from the reheater to drive the gas turbine. The compressed air may with advantage be preheated by exchange with gas turbine exhaust gases. It is calculated that this cycle would result in a heat rate for a 2600 psi, 1050/1050 F at least equal to that of 3500 psi, 1050 F plant with single reheat.

Thermal Scheme of Forced Flow Boiler-Turbine Unit Installations. B. I. Shmoukler. *Teploenergetika* 1959, **6** (Mar.) 8–15 (In Russian).

Two alternatives of unit installations providing for starting at variable steam parameters are discussed.

Some Problems in Thermal Schemes for Supercritical Steam Parameter Unit Installations. A. E. Geltman. *Teploenergetika* 1959, **6** (Mar.) 3–8 (In Russian).

The problems considered are the choice of feedwater temperature, turbine drive of the feed pumps and its connection and the vacuum in the condenser.

The Free Piston Engine and the Mixed Steam Cycle. C. G. Henson. *Steam Engr.* 1959, **28** (Mar.) 183–6.

It is shown that by a combination of free piston engine and steam cycle

the efficiency can be increased from 28 per cent of the steam cycle alone to 33 to 34 per cent of the combination.

The Use of Solar Energy in the U.K. H. Heywood. *J. Inst. Fuel* 1959, **32** (Mar.) 110–2.

The possibilities of using solar energy under the climatic conditions prevailing in Great Britain are discussed. It is believed that half the hot water load over the whole year could be taken by solar heaters and in summer often the whole load.

Fuel Cells. E. Gorin and H. L. Recht. *Blast Furn. and Steel Plt.* 1959, **47** (Feb.) 206–9.

The development of fuel cells in recent years is reviewed, particularly those operating at high temperatures (above 500 C) and the cell designed by the authors is described. The economics of these cells are discussed which are largely a function of their efficiency; this may reach up to 70 to 75 per cent. It is contended that fuel cells may be competitive with nuclear power over a longer period than conventional steam power plants.

Gas Turbines and Waste Heat Boilers. F. W. Foley. *Power* 1959, **103** (Mar.) 59–61.

At the El Centro power station in Colombia several old turbines and boilers were replaced by two natural gas fired single-cycle 5 Mw gas turbines each discharging 396 klb/h of exhaust at 840 F to an associated waste heat boiler generating 35,000 lb/h of steam at 250 psi and 480 F; this output is raised to 80,000 lb/h by supplementary gas or oil firing. A third waste heat boiler is separately fired. The steam is supplied to an existing 5 Mw condensing turbogenerator, turbine driven auxiliaries and process. The calculated heat rate is 25 per cent lower than for an equivalent extraction steam turbine installation and 6 per cent cheaper in capital costs.

Transportable Heating Stations. Pacemakers for District Heating Stations. Anon. *V.D.I. Nachr.* 1959, **13** (Feb. 28) 4.

Hamburg power stations possess 3 transportable power stations to supply new factories and housing estates with power, heating and hot water until connection to the large heat-power stations is economically justified. The water-tube boiler is oil fired and has an output of 26 klb/h of steam at 325 psi and 665 F with a thermal efficiency of 84 per cent. The steam can be used either directly to drive a turbogenerator or it is reduced in pressure to 60 psi and desuperheated to 355 F for heating purposes. The Hamburg district heating system is the largest in Europe with an annual consumption of 6×10^{12} Btu; it has made possible an overall efficiency of power and heat generation of 86 per cent.

Materials and Manufacturing Processes

Power Piping Design. F. M. Kamarck. *Heat. Pip. Air Cond.* 1958, **30** (Nov.) 95–104.

The article discusses some of the engineering problems that arose and the development that went into the design of the piping system for the new 750 Mw Memphis plant (three 250 Mw turbo-generating units). The many factors involved and their interrelationship in the sizing and design of the main steam piping are evaluated; steam conditions selected were 2625 psig and 1053 F. The two-pipe system layout with a cross-over uses hollow forged chrome-moly pipe for straight runs, with turned and bored piping for bends. Specification data of the steam piping materials and layout diagrams are given.

From *C.E.G.B. Digest* 1959, **11** (Feb. 28) 487.

Instruments and Controls

Process Control and Automation. T. J. Williams. *Ind. Engng. Chem.* 1959, **51** Pt. II (Mar.) 432–6.

The review of literature published during 1958.

Automatic Control of Steam Generators. R. Quack. *Mitt. V.G.B.* No. 58 1959, (Feb.) 1–11 (In German).

The first part discusses theory and practice of automatic control installation for steam generators, distinguishing between "inner" control (temperature, pressure, water level, firing rate, feedwater flow, mill output) and "outer" control (output) in integrated networks. The second part discusses the desirable and possible characteristics of control circuits and the relationship between elaborateness of the control installations and the economics of the whole plant.

Atmospheric Pollution by Solid Particles. Measuring Significant Particle Surface Area by Charge Transfer. D. H. Grindell. *Engineering* 1959, **187** (Mar. 13) 350–1.

For the study of industrial fog the number, total surface area and chemical composition of airborne particles are required. An instrument operating on the principles of electrostatic precipitation has been developed in which the particles are first charged by a high-voltage corona and then collected on an electrode where the charge is deposited. The particles carry a charge roughly proportional to their surface area so that the charge current will give an indication of the total surface area of the particles.

Nuclear Energy

Development of a National Atomic Energy Program. Sir John Cockroft. *Atom* 1959, (Mar.) 9–12.

In this lecture to the University of Ankara the development of the British Atomic Energy program was reviewed with the suggestion that it may serve as a model for similar developments in other countries. In Great Britain this started with the production of radioisotopes in Gleep, Bepo and, lately, Dido and investigations into their further use, followed by the building of further research reactors for numerous special purposes and the planning and inauguration of a nuclear power program.

Nuclear Energy in the Netherlands. Anon. *Atomic World* 1959, **10** (Feb.) 68–72.

The organization of nuclear energy research and development is set out and the progress made so far described. There are two reactors under construction, one a swimming pool type (100 kW) for the University of Delft and the other a high flux reactor (20 Mw) for Petten, where the main atomic research center will be located.

Effect of Radiation on Corrosion of Structural Material by Molten Fluorides. G. W. Keilholtz, J. G. Morgan and W. E. Browning. *Nucl. Sci. Engng.* 1959, **5** (Jan.) 15–20.

These studies have shown no changes in corrosion of Inconel that can be the result of radiation damage, nor occurred changes in the fuel mixtures attributable to radiation other than normal burnup of uranium.

Cooperative Research on Gas-Cooled Nuclear Reactor. Anon. *Elect. Times* 1959, **135** (Feb. 19) 291.

The countries represented in O.E.E.C. and Great Britain have concluded an agreement by which Euratom and the U.K. will each contribute £4.34 million to a joint high-temperature reactor project to be carried out at Winifrith Heath. The project has been given the name "Dragon" and it is envisaged to work with fuel surface temperatures of over 1000 C (1800 F) and helium at 10 at as cooling gas with an outlet temperature of 750 C (1400 F); the heat output will be 10 Mw. The fuel elements will consist of a mixture of graphite (moderator) and U 235 and Th 232 contained in a graphite sheath.

Atomic Review. Fast Flux. Anon. *Engineering* 1959, **187** (Mar. 13) 334–6.

The review tabulates the fast reactors in U.S.A., U.S.S.R., and Great Britain and their main design data and also deals with: 1. Coupled fast-thermal system; 2. Fast liquid fuel system; 3. Fast reactor fuel charging; 4. Fast reactor cross sections; 5. Dounreay fast reactor tests; 6. U. S. fast reactors; 7. Fast reactor hazards; 8. References.

High Temperature Gas-Cooled Reactor Project. Anon. *Engineer* 1959, **207** (Mar. 13) 415–7.

The 10 Mw (thermal) research reactor of the high temperature gas cooled type to be built and operated in collaboration by Euratom and Great Britain is described. Details are given of fuel element design, core, primary and secondary cooling circuits, controls, charge/discharge machine and the research program.

Operating Characteristics of a Graphite-Moderated Subcritical Assembly. R. E. Uhrig. *Nucl. Sci. Engng.* 1959, **5** (Feb.) 120–6.

The determination of the basic operating characteristics of the assembly used at Iowa State College is described and discussed.

Liquid-Metal Fueled Power Reactors. S. B. Hosegood and P. M. C. Lacey. *Engineering* 1959, **187** (Mar. 6) 313–8.

This review sets out the advantages of the liquid-metal fueled reactor and discusses in detail: 1. Types of reactors; 2. Liquid-metal fuels and fertile media; 3. Processing; 4. Thermal breeder power reactors; 5. Fast breeder reactors; 6. Future prospects.

Boiling Effects in Liquid Cooled Reactors. H. A. Roberts and R. W. Bowring. *Nucl. Pwr.* 1959, **4** (Mar.) 96–101, 118.

This second part deals with boiling heat transfer, effects of various types of boiling, correlations for calculating fuel element temperatures and reactor safety limits set by burnout.

Plutonium Recycle in the Calder Hall Type Reactor. L. J. Barbieri, J. W. Webster and Ken Tang Chow. *Nucl. Sci. Engng.* 1959, **5** (Feb.) 105–19.

Three possible schemes of recycling plutonium produced in the reactor have been studied. The scheme in which the Pu is blended with fresh natural uranium for subsequent use is the most economic when based on a burnup of 8800 MWd/t.

Process Heat from Nuclear Reactors. H. Perry and J. P. McGee. *Chem. Engng.* 1959, **66** (Feb. 23) 143–8.

The application of heat from a nuclear reactor for the production of ammonia and acetylene, gasification of coal, low-temperature carbonization of coal, blast furnaces and melting of non-ferrous alloys is discussed. Feasibility studies carried out by the U.S.A.E.C. and U.S.B.M. are described.

Grinding, Screening and Filtering

Size Reduction. L. T. Work. *Ind. Engng. Chem.* 1959, **51** Pt. II (Mar.) 395–7.

The review of literature published during 1958.

Grinding at Supercritical Speeds in "Ball" Mills. H. E. Rose and N. D. Trbojevic. *Nature* 1959, **183** (Mar. 21) 813–4.

Grinding conditions in a laboratory "Ball" mill running at supercritical speed have been studied. It could be shown that a small part of the grinding effect under these conditions is obtained by a sliding action between the mill shell and the charge, the greater part by lifting of the charge to 45° above the horizontal and the collapse of the leading edge of the charge in a coherent mass on to the lower portion of the charge. This blow produces a

grinding effect on the charge without affecting the mill wall and thus considerably reduces wear of the mill liners.

Grinding and Drying Problems of Low-grade Fuels in Belgian p.f.f. Power Stations. J. Danze and L. Delvaux. *Institut Francais des Combustibles et de l'Energie. Solid Fuel and Pulverised-Fuel Conf. 1957; Paper,* No. 4.02. C.E. Trans. 1304.

A description is given of the methods currently used in Belgium for grinding and drying low-grade fuels for steam-generators of various capacities. Some special problems connected with the nature of the fuel, methods of predrying, grinding mills and the effect of low-grade fuels on the cost of the grinding operation are discussed.

From *C.E.G.B. Digest* 1959, **11** (Feb. 28) 492.

Mixing. J. H. Rushton. *Ind. Engng. Chem.* 1959, **51** Pt. II (Mar.) 392–4.

The review of literature published during 1958.

Filtration. H. P. Grace. *Ind. Engng. Chem.* 1959, **51** Pt. II(Mar.) 354–61.

The review of literature published during 1958.

Analysis and Testing, Research

The Determination of Organic Substances in Power Station Water. A. Gubin and W. Hoffmann. *Mitt. V.G.B.* No. 58 1959 (Feb.) 34–7 (In German).

The method for determining the organically bound carbon in water is described.

The Study of Coal Surfaces. J. Platt. *Coll. Guard.* 1959, **198** (Mar. 19) 369–71.

A new technique for studying coal surfaces under the electron microscope using carbon replicas is described and the results obtained are illustrated by microphotographs. These show that the clarity of the micro-structure obtained by the new technique is much better than that obtained by previous methods.

Photometric Determination of Dissolved Oxygen on the Basis of the Winkler Method. G. Resch. *Mitt. V.G.B.* No. 58 1959, (Feb.) 31–4 (In German).

The method of determining photometrically the iodine concentration equivalent to the oxygen content in the water and the calibration of the apparatus are described. The method is sensitive down to O_2 concentration of 0.01 ppm.

The Collection and Turbidimetric Estimation of Sulfur Trioxide in Flue

Gases. D. H. Napier and M. H. Stone. *J. Appl. Chem.* 1958, **8** (Dec.) 787–93.

The improved absorption apparatus for SO_3 and the improved method for its determination are described.

Power Generation and Power Plant

Economic Trends in the Generation of Electric Energy in the Detroit Edison System. G. A. Porter and D. E. Hart. *Combustion* 1959, **30** (Mar.) 30–7.

The first part deals with cost reductions achieved in recent years by the adoption of large units, higher pressures and temperatures, reheat and other engineering improvements. On the basis of this experience the possibilities of achieving similar increases in efficiency in future are discussed in the second part. The supercritical pressure cycle does not appear to justify the very much higher investment costs, but the use of a liquid heat transfer medium for a double reheat cycle or of an air-steam binary cycle would considerably lower the station heat rate. The problems involved in either of these cycles are briefly outlined. It is not anticipated that future increases in steam cycle efficiencies will be as great as those during the past 25 years.

Power Generation and Integrated Operation in West Germany 1949/1958. K. Klöss. *BWK* 1959, **11** (Apr.) 160–2 (In German).

Installed capacity in public and industrial (mainly colliery) power stations increased from 10,038 Mw at the end of 1948 to 22,700 Mw at the end of 1958. Installed capacity in public power stations at the end of 1958 was 14,200 Mw, in industrial and railway stations 8500 Mw. The average consumption increased by 12 per cent but tended to fall off: at times of peak consumption the reserve was hardly more than 10 per cent. Increasing use has been made of power exchange with other European countries.

Combined Heat and Power Generation. F. J. Molter. *BWK* 1959, **11** (Apr.) 162–4 (In German).

District heating systems have increased fourfold during the past 10 years and over 50 towns in West Germany have installed combined heat and power stations. Of 68 stations, three distribute heat obtained from industrial power stations and operate without electricity generation. Three gas turbine plants are under construction for combined heat and power generation; one of them is a combination of air turbine (12.5 Mw) and steam turbine (13.75 Mw).

Heat and Power Generation in Public Heat-Power Stations. Pt. IV. Planning and Operation of Heat-Power Plants. T. Geissler. *Energie* 1959, **11** (Mar.) 93–103 (In German).

The calculation of heat consumption of district heating systems and of the most economic turbine size is presented. The various possibilities of using back-pressure and condensing turbines in different arrangements according to given requirements are discussed.

Electrical Performance of the Philo Supercritical Unit. A. S. Grimes and J. A. Tillinghast. *A.S.M.E. Preprint* No. 58-A-297 1958 (Dec.) 9 pp.

Some further details are given of the factors contributing to the actual heat rate being higher than the design heat rate. These concern the excessive leakages at the feed pumps, the rate of flue gas recirculation, deposits of copper oxide on the blades of the high pressure turbine and investigations are in progress to eliminate these difficulties. The actual heat rate from November 1957 to May 1958 was 8886 Btu/kWh.

Two-Furnace Reheat Type Steam Generator at River Rouge Station of Detroit Edison Company. G. I. Smith. *Heat Engng.* 1959, **34** (Jan./Feb.) 2–5.

The third unit at River Rouge station is one of the largest in the world and recently started operating. It consists of a 2000 klb/h boiler and a 321.5 Mw turbogenerator. The boiler is of the two-furnace coal-fired, natural circulation type generating steam at 2450 psi and 1050/1000 F. Each side of the unit has an identical furnace, radiant superheater and boiler section, but one contains a convection reheater and the other a convection superheater. The radiant superheater forms the roof, front wall and part of the side walls of the furnace. The flue gases pass the economizers, hot end rotary air preheaters, precipitators, i.d. fans and cold end regenerative preheaters before entering the stack at a temperature of 206 F. The 24 intervane burners are arranged in 3 rows of 4 in each furnace; a further 4 burners underneath are for the firing of blast furnace gas. Superheated steam temperature regulation is by control condensers, the reheated steam temperature is controlled by the rate of firing.

Initial Operating Experience with Monotube Once-Through Boiler at Subcritical Pressure. J. D. Williamson. *A.S.M.E. Preprint* No. 58-A-286 1958 (Dec.) 8 pp.

Operating experiences and difficulties encountered during the three

months of operation of the first of two subcritical monotube boilers at the F.M. Tait power station (see also abstract 2896, 1958) are reported. These relate to 1. Air ingress into the control fluid system; 2. Sticky valves; 3. Deaerator damage; 4. Condenser leakage; 5. Evaporating tube failures; 6. Uneven distribution to evaporating tube sections; 7. Pre-operation cleaning of boiler with concentrated citric acid; 8. Feedwater requirements and actual data (total dissolved solids, pH control, dissolved oxygen, silica and iron).

TVA—Coal Power. W. Bradbury. *Coal Utilization* 1959, **13** (Mar.) 18–26.

A review is presented of the capacity installed in the 8 large steam power stations of the TVA system, the size of boilers, steam pressures and temperatures, coal consumption of each station, sources of coal supply, coal handling plants at each station, rates and revenues.

Electric Power from Low Quality Coal and Wash Water. R. Haenisch. *Energie and Tech.* 1959, **11** (Jan.) 7–10 (In German).

Wölfersheim power station has been built to utilize lowgrade brown coal from the neighboring open-cast mines. The brown coal has a high ash and moisture content so that its C.V. averages only 1500 kcal/kg. The power station contains two units each consisting of a Benson boiler generating steam at 145 atü and 530 C with reheat to 470 C and a 30 Mw turbogenerator. The brown coal is dried in the feed chute to the mill (4 per boiler) by flue gases at a temperature of 900 C and injected tangentially at each corner of the furnace with air preheated to 350 C. Fly ash is separated in electrostatic precipitators. Feed-water is preheated by steam from a pond formed in an old mine; on its return it drives a 305 kW turbogenerator to recover some of the power expended in the circulating pumps. The actual net heat rate is 2800 kcal/kWh. In the Ruhr region the huge masses of sewage sludge are now being converted to useful raw materials. A sludge drying and preparation plant divides it into one part of high iron content and one part of high C.V. (4400 kcal/kg) content to be used as fuel in brick works and boiler furnaces.

Combustion and Bio-Oxidation Combined in Waste Plant at Chemstrand. D. T. Laura. *Pwr. Engng.* 1959, **63** (Apr.) 80–2.

The waste from the nylon producing plant at Pensacola, Florida, is divided into three categories. The concentrated waste is burned together with natural gas in the power plant to

generate heat, a second stream is disposed of in an incinerator by burning, using natural gas as auxiliary fuel, and the third stream is brought to boiling in an evaporator by submerged combustion of gas and the vapors pass to a chimney. The effluent from submerged combustion is mixed with raw process waste, neutralized, mixed with river water, treated with bio-oxidation effluent, active sludge organisms and air in a tank for a detention time of 12 h. Clarified effluent is further treated before discharge to the river. This treatment has successfully prevented pollution of the Escambi River.

Steam Plant for Nuclear Power Stations. J. R. Finniecome. *Mech. Wrld.* 1959, **139** (Apr.) 158–62.

This last part compares the auxiliary turbines, gas circulators and their drives and capital costs of gas-cooled graphite moderated nuclear power stations as a function of their net electrical output.

Materials and Manufacturing Processes

High Temperature Oxidation of Chromium-Nickel Steels. D. Caplan and M. Cohen. *Corrosion* 1959, **15** (Mar.) 57–62.

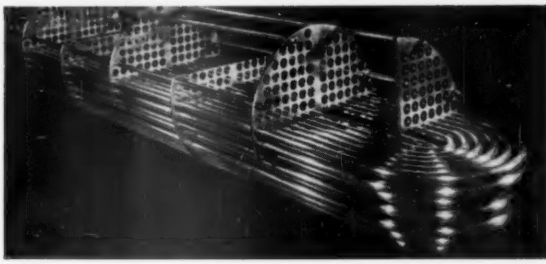
The scaling effect of dry and moist air on 4 types of stainless steel at temperatures up to 2000 F was studied. After an initial period of protection by a thin film of Cr formed during treatment prior to the tests the oxidation curves show breaks indicating periods of rapid oxidation due to the disruption of the protective scale. Accumulation of silica at the metal-scale interface contributes to this disruption. Moisture in the air was found to increase the scaling rate of Ni-Cr steels.

Oak Ridge Report on Graphitization in H-P Steam Lines. C. H. Mahoney and W. S. Dritt. *Pwr. Engng.* 1959, **63** (Mar.) 68–9.

The power station at the Oak Ridge gaseous diffusion plant contains three boilers rated at 750 klb/h at 1325 psi and 935 F connected to a common steam header. After 13 years of operation serious graphitization was detected in the carbon-molybdenum forged steel reducers. Although repairs would have been possible it was considered more economical to replace all affected parts by $1^1/_4$ Cr–0.5 per cent Mo steel.

Graphitization Failures in Piping. J. B. Nuchols and J. R. McGuffey. *A.S.M.E. Preprint* No. 58-A-56 1958 (Dec.) 3 pp.

This discusses the graphitization problem experienced in the pipelines of the boiler plant at Oak Ridge.



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Edited by David S. Hibbard, Metallurgical Engineer
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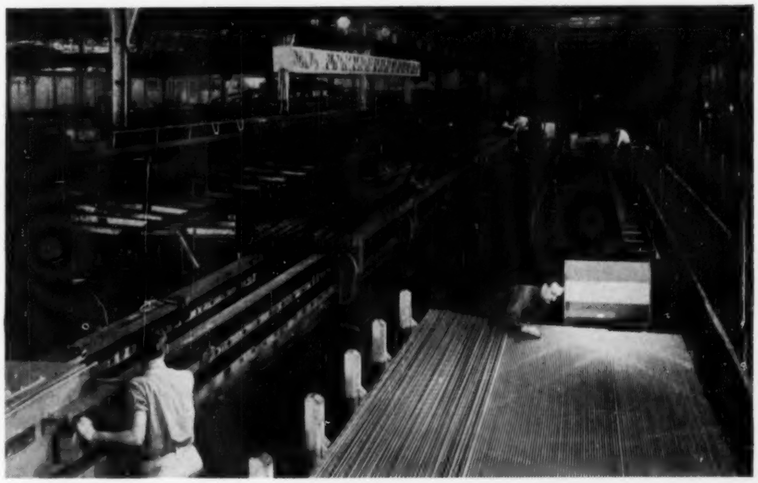

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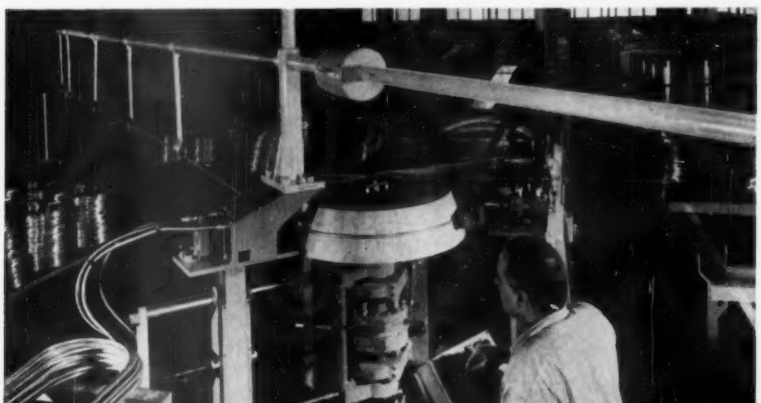

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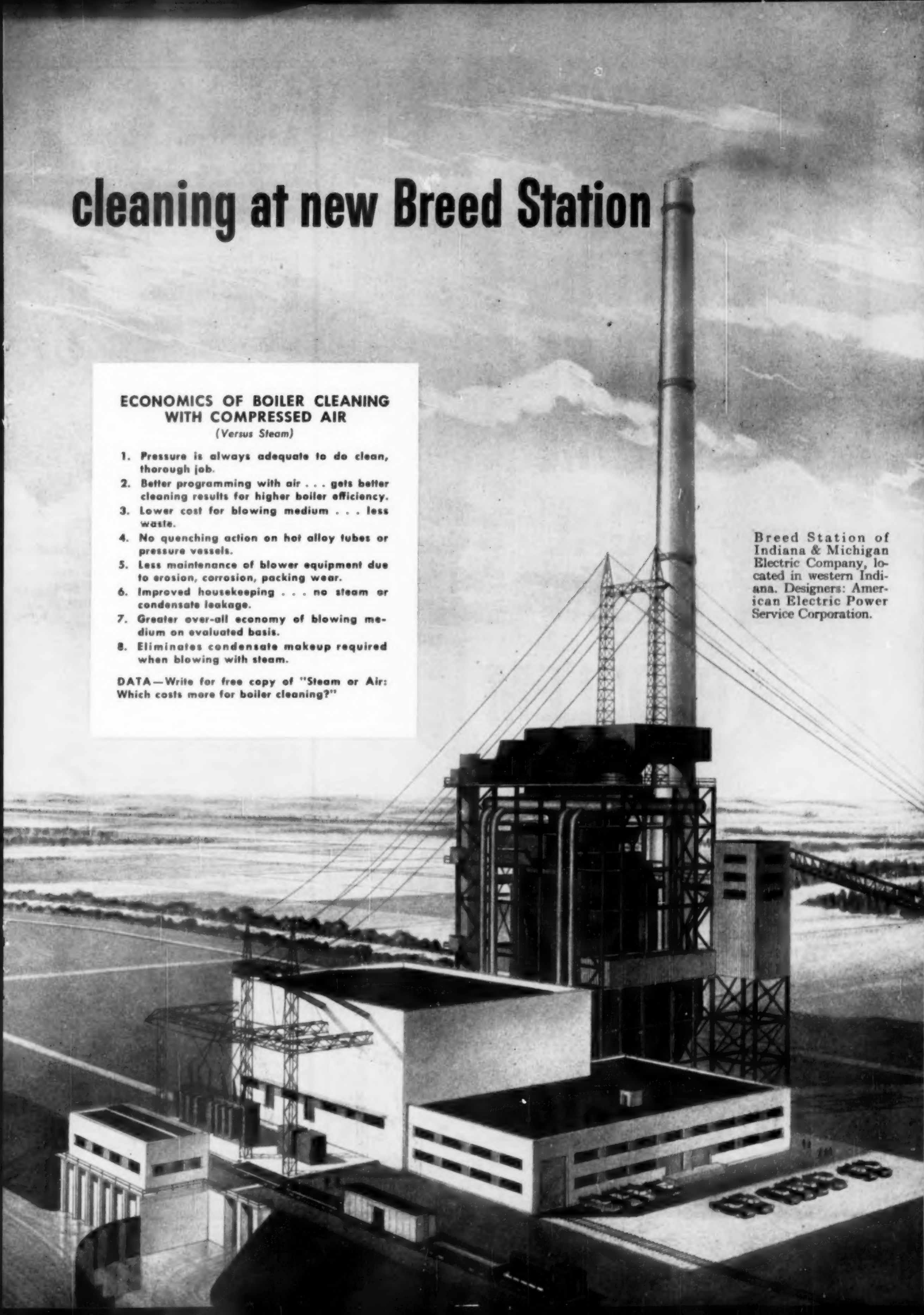

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(Continued on page 71)

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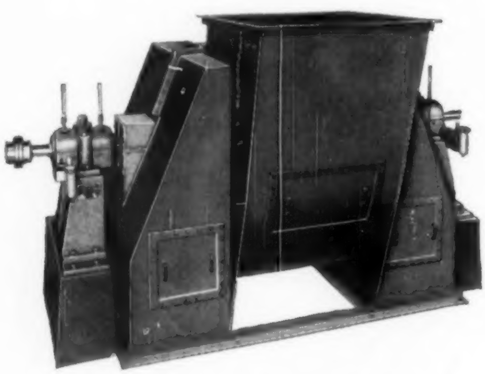

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